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Solar Programs Office

FCHART
Version 4.1

A Design Program for Solar Heating Systems

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Assistance and Information

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Acknowledgement

This manual describes an adaptation of FCHART version 4.1, adapted by the Solar Programs Office of Public Works Canada to operate on IBM or CDC computer systems and to utilize weather and solar data for 97 Canadian locations. This material is based on EES Report 50 prepared by the Solar Energy Laboratory, University of Wisconsin.

The FCHART program and f-chart design method on which it is based were developed at the Solar Energy Laboratory, Engineering Experiment Station, University of Wisconsin. The research and program development were supported by the Solar Heating and Cooling Development Branch, Office of Energy Conservation and Solar Applications, U.S. Department of Energy.

User Responsibility

Users are responsible for the validity of the information generated by the FCHART 4.1 program. Consequently the program should not be used by those who do not comprehend the technical field to which this program applies. Neither Public Works Canada nor any person acting on behalf of the Department makes any warranty or assumes any responsibility for accuracy, completeness or usefulness of any information generated by this program.

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Preface

FCHART 4.0 incorporates several design methods for active solar heating and heat pump heating systems which have been developed at the University of Wisconsin during the last few years. In all cases system performance is calculated from equipment characteristics and monthly average meteorlogical data. The interactive program allows the user to describe the system to be studied and can perform thermal and economic analyses.

The users manual is divided into three main sections. The first section entitled "Meet FCHART" acquaints the first-time user with FCHART. FCHART's capabilities are briefly described and a sample FCHART session is presented. The second section is a users guide providing detailed explanations of FCHART's capabilities and how to access them. This section is good reference for the user who is somewhat familiar with FCHART. For those interested in the design methods and assumptions incorporated in FCHART, Section 3 has been provided.

NOMENCLATURE*

A_c	collector area
$\overline{COP}$	average heat pump coefficient of performance
c_p	specific heat
C_S	capacitance of storage
DD	degree days
F_{DHW}	fraction of the domestic hot water load met by solar
F_{gnd}	view factor from a collector reciever to the ground
F_{NP}	fraction of the total load which is non-purchased energy
F_R	collector heat removal efficiency factor
F_RU_L	negative slope of the collector efficiency curve
$F_R(\tau\alpha)_n$	intercept of the collector efficiency curve
$F_R(\overline{\tau\alpha})$	intercept corrected for non-normal solar incidence
$F_R'U_L$	modified F_RU_L accounting for collector-storage heat exchanger
$F_R'(\tau\alpha)_n$	modified $F_R(\tau\alpha)_n$ accounting for collector-storage heat exchanger
F_RU_L'	modified F_RU_L accounting for collector pipe or duct heat losses
$F_R(\tau\alpha)_n'$	modified $F_R(\tau\alpha)_n$ accounting for collector pipe or duct heat losses
$F_R^*U_L$	modified F_RU_L accounting for air duct leaks
$F_R^*(\tau\alpha)_n$	modified $F_R(\tau\alpha)_n$ accounting for air duct leaks
F_{SH}	fraction of the space heating load which is non-purchased energy
F_{SKY}	view factor from the collector reciever to the sky
F'	collector efficiency factor
G	total instantaneous radiation on a horizontal surface
G_b	instantaneous beam radiation on a horizontal surface
G_c	critical level of radiation necessary for net useful energy collection
$\overline{G}_c$	monthly average critical level which determines the correct energy collection

---

* This list contains most but not all of the nomenclature used in this section. Some additional symbols are defined locally.

G_d	instantaneous diffuse radiation on a horizontal surface
G_T	instantaneous radiation on an inclined surface
$\overline{H}$	monthly average daily radiation on a horizontal surface
$\overline{H}_{COLL}$	monthly average daily radiation on a collector surface during operation
$\overline{H}_d/\overline{H}$	monthly average diffuse fraction
$\overline{H}_T$	monthly average daily radiation on an inclined surface
L	energy load
L_R	ratio of air leakage flowrate to collector outlet flowrate
$\dot{m}$	mass flowrate
M_w	monthly domestic hot water usage (mass)
N	number of days in a month
Q_{ATM}	energy absorbed by the evaporator of an air-to-air heat pump
$\dot{Q}_{CAP}$	heat pump capacity
Q_D	energy delivered to the load by the delivery device
Q_D'	energy delivered to the load by the delivery device and the primary auxiliary
Q_{DHW}	energy supplied to the DHW load by the solar system
Q_{LS}	energy losses from storage
Q_{PUR}	purchased energy
Q_S	solar energy supplied from storage to the load
$Q_{S\|max}$	maximum energy that can be supplied from storage when the delivery device meets the load
Q_{SH}	energy supplied from storage to meet the space heating load
Q_u	net useful energy collection
$\overline{R}$	ratio of average daily radiation on a tilted surface to that on a horizontal surface for an average day
R_b	the ratio of instantaneous beam radiation on a tilted surface to that on a horizontal surface

t	time
T	storage temperature
$\bar{T}$	average monthly storage temperature
T_a	ambient temperature
$\bar{T}_{da}$	monthly average daytime ambient temperature
T_{av}	collector average plate temperature
T_b	boiling temperature of storage medium
T_{env}	environmental temperature for storage losses
T_F	final monthly storage temperature
T_i	collector inlet temperature
T_I	initial monthly storage temperature
T_{main}	water mains temperature
T_{min}	minimum useful storage temperature
T_o	collector outlet temperature
T_R	load heat exchanger cold side inlet temperature
$\bar{T}_S$	monthly average supply temperature from storage if the delivery device operated continously whenever the load occurred
T_{set}	desired DHW set temperature
U_L	collector loss coefficient
$(UA)_A$	DHW auxiliary tank loss conductance
$(UA)_i$	collector inlet pipe or duct loss conductance
$(UA)_L$	building overall loss conductance
$(UA)_o$	collector outlet pipe or duct loss capacitance
$(UA)_T$	storage tank overall loss conductance
Δt	period of time within a month that the load occurs
Δt_m	length of time in a month

α	absorptance of the collector reciever
β	collector slope
εC_{min}	effectiveness-minimum capacitance rate of a heat exchanger
θ	incidence angle of beam radiation
θ_c	CPC half acceptance angle
θ_z	zenith angle
η	collector thermal efficiency
ρ	ground reflectance
ρ_d	reflectance of a cover system for diffuse radiation
τ	transmittance of a cover system
$(\tau\alpha)$	transmittance-absorptance product (optical efficiency) of a collector
$(\overline{\tau\alpha})$	monthly average transmittance-absorptance product
$(\overline{\tau\alpha})/(\tau\alpha)_n$	ratio of monthly average transmittance-absorptance product to transmittance-absorptance product at normal incidence
$(\tau\alpha)_d/(\tau\alpha)_n$	transmittance-absorptance product ratio for diffuse radiation
$(\tau\alpha)_n$	transmittance-absorptance product at normal incidence
$(\tau\alpha)_r/(\tau\alpha)_n$	transmittance-absorptance product ratio for ground-reflected radiation
$\overline{\phi}$	monthly average utilizability based upon total incident radiation
$\overline{\phi}_{max}$	monthly average utilizability if the average collector inlet temperature were equal to $\overline{T}_S$
ϕ_R	monthly average utilizability based upon incident radiation when the collector operates

+ superscript - positive values only

• above a symbol - a rate

DHW subscript - refers to domestic water heating

SH subscript - refers to space heating

SECTION 1 - MEET FCHART

CHAPTER 1

INTRODUCTION

FCHART is a versatile computer program for the analysis and design of active solar and heat pump heating systems. This self-explaining interactive program allows the user to describe the system under analysis easily and provides straightforward tables of performance results. Utilizing methods developed at the University of Wisconsin to estimate long-term average system performance, FCHART features life-cycle cost analysis, system optimization, and weather data handling capabilities.

SYSTEM TYPES

- Space Heating
  - Air- or Liquid-based Active Solar
  - Ambient source or Solar-assisted Heat Pumps
- Domestic Water Heating
  - Combined Space and Water Heating
  - Water Heating Only Systems
- Process Heating
  - Closed-loop Heat Delivery through Heat Exchanger or Heat Pump

ANALYSIS OPTIONS

- Collectors
  - Flat-Plate
  - Compound Parabolic Concentrators (Liq.-based systems only)
  - Imaging Concentrators (1- or 2-Axis Tracking; Liq. systems only)
- Collector-Storage Loop
  - Pipe or Duct Heat Losses
  - Air Duct Leaks
  - Heat Exchanger
- Storage Device
  - Liquid Tank
  - Rock Bed
  - Phase-Change Material (Air-based Space Heating)
- Storage-Load Heat Delivery
  - Heat Exchanger
  - Heat Pump (Liquid-based Systems)

- Load Calculation Methods
    - Space Heating
        - User-supplied monthly loads
        - UA-degree day
    - Water Heating
        - Based upon usage, set temperature, and mains temperature (includes auxiliary tank losses)
    - Process Heating
        - User-supplied monthly totals

- Auxiliary (Solar System Back-up)
    - Conventional Fuel (Gas, Elec., Oil)
    - Ambient-Source Heat Pump (space heating)

- Economics
    - Life-Cycle Purchase and Operating Costs
    - Comparisons Between Alternatives
    - Optimization of any system parameter

The best way to become acquainted with FCHART is to try the example presented in Chapter 2. After you have become familiar with the program, you may wish to peruse the remainder of the manual. Section II is a user's guide which provides more detailed explanations of FCHART's capabilities and how to access them. Section III describes the methods used in the thermal analysis sections of the program and gives references for obtaining further information.

CHAPTER 2

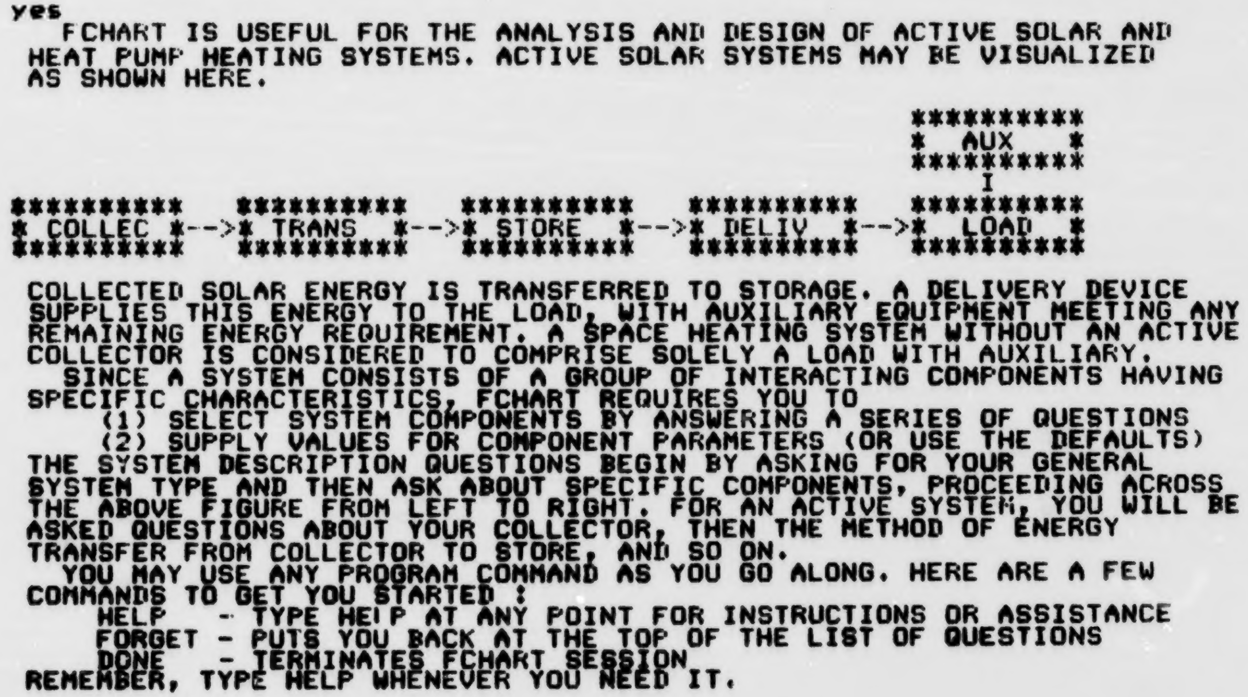
EXAMPLE RUN

To run this analysis of a liquid-based space heating system, sit down at a terminal and start the program. In the following pages, FCHART output will be set off from the text by blank lines. Your responses will appear in the text in underlined capitals. FCHART begins by asking if you would like instructions and offers you your choice of three responses: YES, NO, or QUICK.

```
  WOULD YOU LIKE INSTRUCTIONS (YES,NO,QUICK) ?
```

Since the program is new to you, answer YES. This produces the following explanation :

```
  FCHART IS USEFUL FOR THE ANALYSIS AND DESIGN OF ACTIVE SOLAR AND
AND HEAT PUMP HEATING SYSTEMS. ACTIVE SOLAR SYSTEMS MAY BE VISUALIZED
AS SHOWN HERE.
```



```
yes
   FCHART IS USEFUL FOR THE ANALYSIS AND DESIGN OF ACTIVE SOLAR AND
 HEAT PUMP HEATING SYSTEMS. ACTIVE SOLAR SYSTEMS MAY BE VISUALIZED
 AS SHOWN HERE.

                                                     **********
                                                     *  AUX   *
                                                     **********
                                                         I
**********   **********   **********   **********   **********
* COLLEC *-->* TRANS  *-->* STORE  *-->* DELIV  *-->*  LOAD  *
**********   **********   **********   **********   **********

 COLLECTED SOLAR ENERGY IS TRANSFERRED TO STORAGE. A DELIVERY DEVICE
 SUPPLIES THIS ENERGY TO THE LOAD, WITH AUXILIARY EQUIPMENT MEETING ANY
 REMAINING ENERGY REQUIREMENT. A SPACE HEATING SYSTEM WITHOUT AN ACTIVE
 COLLECTOR IS CONSIDERED TO COMPRISE SOLELY A LOAD WITH AUXILIARY.
   SINCE A SYSTEM CONSISTS OF A GROUP OF INTERACTING COMPONENTS HAVING
 SPECIFIC CHARACTERISTICS, FCHART REQUIRES YOU TO
      (1) SELECT SYSTEM COMPONENTS BY ANSWERING A SERIES OF QUESTIONS
      (2) SUPPLY VALUES FOR COMPONENT PARAMETERS (OR USE THE DEFAULTS)
 THE SYSTEM DESCRIPTION QUESTIONS BEGIN BY ASKING FOR YOUR GENERAL
 SYSTEM TYPE AND THEN ASK ABOUT SPECIFIC COMPONENTS, PROCEEDING ACROSS
 THE ABOVE FIGURE FROM LEFT TO RIGHT. FOR AN ACTIVE SYSTEM, YOU WILL BE
 ASKED QUESTIONS ABOUT YOUR COLLECTOR, THEN THE METHOD OF ENERGY
 TRANSFER FROM COLLECTOR TO STORE, AND SO ON.
   YOU MAY USE ANY PROGRAM COMMAND AS YOU GO ALONG. HERE ARE A FEW
 COMMANDS TO GET YOU STARTED :
      HELP   - TYPE HEIP AT ANY POINT FOR INSTRUCTIONS OR ASSISTANCE
      FORGET - PUTS YOU BACK AT THE TOP OF THE LIST OF QUESTIONS
      DONE   - TERMINATES FCHART SESSION
 REMEMBER, TYPE HELP WHENEVER YOU NEED IT.
```

Now you know that FCHART asks you questions in order to determine what kind of system you have and how you want to model it. You also know three commands: HELP, FORGET, and DONE. There are many more commands which you may find out about using the EXPLAIN command. But for the moment, it is only necessary for you to concern yourself with the system description queries. The questions you will be asked depend on the answers you give. If you specify liquid-based space heating, for example, the program will not ask you if you have a rock bed. The first question is

```
WHICH SYSTEM TYPE WOULD YOU LIKE TO CONSIDER (PROC,SPACE,SDHW,DHW) ?
```

If you do not understand what PROC, SPACE, SDHW, and DHW mean, you may type HELP to get the following explanation.

```
help
     THE OPTIONS ARE
            PROC - PROCESS HEATING
            SPACE - SPACE HEATING (ONLY) SYSTEM
            SDHW - COMBINED SPACE AND DOMESTIC WATER HEATING
            DHW - DOMESTIC HOT WATER (ONLY) SYSTEM
   WHICH SYSTEM TYPE WOULD YOU LIKE TO CONSIDER (PROC,SPACE,SDHW,DHW) ?
```

The appropriate answer for this example run is SPACE. You are then asked to specify whether you have active solar heating.

```
space
  DO YOU HAVE ACTIVE SOLAR SPACE HEATING (ACTIVE,NOACTIVE) ?
```

Again, use HELP to get a clarification of what the options ACTIVE and NOACTIVE mean to FCHART.

```
help
     THE POSSIBILITIES ARE
            ACTIVE - ACTIVE SOLAR SYSTEM USED FOR SPACE HEATING
            NOACTIVE - NO ACTIVE SOLAR SPACE HEATING SYSTEM
                   (ANSWER NOACTIVE FOR HEAT PUMP ONLY SYSTEM)
  DO YOU HAVE ACTIVE SOLAR SPACE HEATING (ACTIVE,NOACTIVE) ?
```

For this liquid-based example system, specify ACTIVE. A NOACTIVE system, involves solely a load and auxiliary and would be the correct specification for a ambient source heat pump heating system.

At this point, you have specified a "system type" -- active space heating. Active systems consist of a collector with transfer, storage and delivery devices, a load, and auxiliary equipment. You will now be asked questions about each of these components, beginning with the collector.

```
active
  DO YOU HAVE A FLAT-PLATE, CPC, OR IMAGING COLLECTOR (FPLATE,CPC,IMAGE) ?
```

Answer FPLATE (use HELP if you don't know what FPLATE means) and you will get the following questions regarding energy transfer from collector to storage.

```
fplate
  DO YOU WANT COLLECTOR PIPE OR DUCT LOSS CALCULATIONS (LOSS,NLOSS) ?
nloss
  DO YOU WANT COLLECTOR AIR DUCT LEAK CALCULATIONS (LEAK,NLEAK) ?
nleak
  DO YOU WANT COLLECTOR-STORE HEAT EXCHANGER CALCULATIONS (HX,NHX) ?
nhx
```

To keep things simple, answers of no losses, no leaks and no heat exchangers are given.

You may answer each question as it is asked or, since you know these three questions, you may answer all three in response to the first one. If you answer all three questions on a single input line, FCHART will not print the second two questions. As you become more familiar with the program, you will probably want to answer more questions "in advance" to save time.

Since you have specified a collector type and selected transfer device options, you must next select a storage device. For the example at hand, you will want to answer LIQ to the question

```
    IS THE STORAGE WORKING FLUID AIR OR LIQUID (AIR,LIQ) ?
```

Presently, the only liquid-based storage device available is a liquid tank. (Air-based systems may have a rock bed or a phase-change unit.) Since a tank is the only possibility, FCHART infers TANK from the response LIQ. To see that this happens, and to get an idea of what your system "looks like" so far, you can type PICTURE (PI or PIC will do) instead of answering the next question. The picture you get shows the system type, collector, transfer options, and storage unit which you have selected.

```
liq
  IS THERE A HEAT EXCHANGER OR A HEAT PUMP BETWEEN STORAGE AND THE LOAD
 (HX,HP) ?
pic


                                                    **********
         SYSTEM TYPE : SPACE                        *  AUX   *
                       ACTIVE                       **********
                                                         I
**********   **********   **********   **********   **********
* COLLEC *-->* TRANS  *-->* STORE  *-->* DELIV  *-->*  LOAD  *
**********   **********   **********   **********   **********
  FPLATE        NLOSS       LIQ
                NLEAK       TANK
                NHX                  ECONOMICS :
```

As you can see, the delivery device, load, and auxiliary components have yet to be specified.

Since you typed PICTURE instead of answering the question

```
   IS THERE A HEAT EXCHANGER OR A HEAT PUMP BETWEEN STORAGE AND THE LOAD
 (HX,HP) ?
```

FCHART asks you again. Let us keep the system simple by answering HX.

The space heating load calculation options are INPUT and UA, as enumerated by the question

```
 hx
    WOULD YOU LIKE TO INPUT TOTAL LOADS OR SUPPLY THE BUILDING UA (INPUT,UA) ?
```

These possibilities are explained by HELP

```
help
     SELECT ONE OF THE FOLLOWING LOAD CALCULATION METHODS:
           INPUT - USER INPUT OF MONTHLY LOAD VALUES
           UA  - SPACE HEATING LOAD CALCULATED FROM BUILDING UA
   WOULD YOU LIKE TO INPUT TOTAL LOADS OR SUPPLY THE BUILDING UA (INPUT,UA) ?
```

For this example, a UA-degree day load should be selected. (Answer UA.)

The last system component is space heating auxiliary. You have a choice between a conventional furnace (FUEL) and an ambient-source heat pump (HP).

```
ua
   DO YOU HAVE HEAT PUMP BACK-UP OR CONVENTIONAL FUEL AUXILIARY (HP,FUEL) ?
```

For this example, specify FUEL. Finally, you can get an economic analysis by answering ECON to the question

```
fuel
   WOULD YOU LIKE AN ECONOMIC ANALYSIS (ECON,NOECON) ?
```

This completes the system description and, since you asked for instructions at the beginning, the following message, picture and additional instructions are printed.

```
econ
   SYSTEM DESCRIPTION COMPLETE


                                                    **********
         SYSTEM TYPE : SPACE                        *  AUX   * FUEL
                       ACTIVE                       **********
                                                        I
**********   **********   **********   **********   **********
* COLLEC *-->* TRANS  *-->* STORE  *-->* DELIV  *-->*  LOAD  *
**********   **********   **********   **********   **********
  FPLATE         NLOSS        LIQ          HX          UA
                 NLEAK        TANK
                 NHX                  ECONOMICS : ECON

   THIS IS THE SYSTEM YOU HAVE SPECIFIED. EACH OF THE COMPONENTS
 SHOWN ABOVE (E.G. COLLECTOR,LOAD,AUX) HAS A LIST OF PARAMETERS
 ASSOCIATED WITH IT. YOU MAY NOW WISH TO LIST PARAMETERS, CHANGE
 PARAMETERS, OR USE ANY PROGRAM COMMAND.
     (1) LIST PARAMETERS BY TYPING LIST FOLLOWED BY A COMPONENT NAME
        (COLLECTOR,TRANSFER,LOAD,ETC.) OR A PARAMETER NAME (L1,C5,A2,
        ETC.). TYPE LIST ALL TO LIST ALL PARAMETERS FOR YOUR SYSTEM.
     (2) CHANGE PARAMETERS BY TYPING A PARAMETER NAME FOLLOWED BY THE
        VALUE YOU WANT (E.G. C1=50). SOME PARAMETERS, SUCH AS COLLECTOR
        SLOPE AND HOT WATER USE, MAY BE VARIED BY MONTH. FOR THESE
        PARAMETERS, YOU MAY SPECIFY EITHER A SINGLE VALUE FOR ALL
        MONTHS OR 12 SEPARATE VALUES (E.G. L2 = 300,400,250,...,350).
     (3) USE LIST COMMANDS TO GET A LIST OF COMMAND NAMES OR EXPLAIN
        TO GET EXPLANATIONS OF EACH COMMAND. USE RUN FOLLOWED BY A
        LOCATION NUMBER TO RUN AN ANALYSIS AND TYPE DONE TO
        TERMINATE YOUR FCHART SESSION.
   TYPE PROGRAM COMMAND OR PARAMETER NAME AND NEW VALUE. YOU MAY WANT
   TO BEGIN WITH LIST ALL. TRY HELP IF YOU GET CONFUSED.
 ?
```

Now that you have answered all of the system description questions, you must use program commands to specify what you want done. To get a feel for what you can do at this point, try listing the parameters relevant to the system you have described, running an analysis, changing a few parameters, and running another analysis. If you have forgotten how to list all parameters, you can type HELP. This gives you

```
 ?
help
     TYPE IN PROGRAM COMMAND OR PARAMETER NAME AND NEW VALUE. USE THE
   FOLLOWING COMMANDS FOR MORE INFORMATION :
        LIST COMMANDS - TO GET THE LIST OF COMMANDS
        LIST ALL - TO LIST ALL PARAMETERS
        LIST PGROUPS - TO LIST THE PARAMETER GROUP (COMPONENT) NAMES
        EXPLAIN - TO GET A SHORT EXPLANATION OF EACH COMMAND
 ?
list all

COLLECTOR PARAMETERS
 C1. COLLECTOR AREA ...................................   50.00 M2
 C2. FR-UL PRODUCT ....................................    4.22 W/M2-DEG C
 C3. FR-TAU-ALPHA (NORMAL INCIDENCE) ..................    0.70
 C6. NUMBER OF COVERS (IF 0, C15 IS USED)..............    2.00
 C7. INDEX OF REFRACTION ..............................    1.53
 C8. EXTINCTION COEFFICIENT X LENGTH (KL)..............    0.04
 C9. INC. ANGLE MOD. CONSTANT (IF 0, C6-C8 USED).....     0.0
 C10. COLLECTOR FLOW RATE * SPECIFIC HEAT/AREA ......    55.00 W/M2-DEG C
 C12. COLLECTOR SLOPE .................................   43.00 DEGREES
 C13. COLLECTOR AZIMUTH ...............................    0.0  DEGREES
 C14. GROUND REFLECTANCE ..............................    0.20
 C15. INCIDENCE ANGLE MODIFIERS (10,20,30,40,50,60,70,80 DEG.)
      1.00  0.99  0.98  0.95  0.90  0.80  0.63  0.37

STORAGE UNIT PARAMETERS
 S1. TANK CAPACITY/COLLECTOR AREA .....................  350.00 KJ/DEG C-M2
 S2. STORAGE UNIT HEIGHT/DIAMETER RATIO ...............    2.00
 S3. HEAT LOSS COEFFICIENT ............................    0.50 W/M2-DEG C
 S4. ENVIRONMENT TEMPERATURE (-1000 FOR TENV=TAMB) ..     20.00 DEG C

DELIVERY DEVICE PARAMETERS
 D1. EPS-CMIN OF LOAD HEAT EXCHANGER .................. 1200.00 W/DEG C
 D2. MINIMUM TEMPERATURE FOR HX OPERATION .............   20.00 DEG C

LOAD PARAMETERS
 L1. BUILDING UA ......................................  275.00 W/DEG C
 L2. ROOM TEMPERATURE .................................   20.00 DEG C

AUXILIARY PARAMETERS
 A1. AUXILIARY FUEL TYPE (1=GAS,2=ELEC,3=OIL) .......      2.
 A2. AUXILIARY DEVICE EFFICIENCY ......................    1.00

ECONOMIC PARAMETERS
 E1. ECONOMIC OUTPUT DETAIL (1,2 OR 3) ................    2.00
 E2. REFERENCE OR COMPARISON SYSTEM (1 OR 2) ..........    1.00
 E3. CALCULATE RATE OF RETURN (YES=1,NO=2) ............    2.00
 E4. INCOME PRODUCING BUILDING (YES=1,2=NO) ...........    2.00
 E5. DEPRC: STR.LN.=1,DC.BAL.=2,SM-YR-DGT=3,NONE=4 ..      1.00
 E6. CONSIDER FEDERAL TAX CREDITS (YES=1,2=NO) ......      1.00
```

```
E7. LENGTH OF ANALYSIS .............................    20.00 YEARS
E8. TAX CREDITABLE SYSTEM BASE COST ................$ 6000.00
E9. NON-TAX CREDITABLE SYSTEM BASE COST ............$    0.0
E10. ANNUAL INCREASE IN PURCHASED ENERGY DEMAND ....     0.0  %/YR
E11. TERM OF MORTGAGE ..............................    20.00 YEARS
E12. DOWN PAYMENT (% OF ORIGINAL INVESTMENT) .......    10.00 %
E13. MORTGAGE ANNUAL INTEREST RATE .................     8.00 %
E14. RESALE VALUE (% OF ORIGINAL INVESTMENT) .......     0.0  %
E15. ANNUAL NOMINAL (MARKET) DISCOUNT RATE .........     8.00 %
E16. EXTRA INSUR.,MAINT. IN YEAR 1 (% OF ORIG.INV.)      1.00 %
E17. ANNUAL % INCREASE IN ABOVE EXPENSES ...........     6.00 %
E18. EFFECTIVE FEDERAL-STATE INCOME TAX RATE .......    35.00 %
E19. TRUE PROP. TAX RATE PER $ OF ORIGINAL INVEST ..     2.00 %
E20. ANNUAL % INCREASE IN PROPERTY TAX RATE ........     6.00 %/YR
E21. STATE CREDIT IN TIER ONE.......................    24.00 %
E22. STATE CREDIT TIER ONE BREAK....................$10000.00
E23. STATE CREDIT IN TIER TWO.......................     0.0  %
E24. STATE CREDIT TIER TWO BREAK....................$10000.00
E25. USEFUL LIFE FOR DEPREC. PURPOSES ..............    20.00 YEARS
E26. % OF ST. LINE DEP. RATE (DC. BAL. DEPRC.) .....   150.00 %

TYPE LIST FLDATA FOR FUEL COSTS
?
```

Note that no transfer device parameters are listed since no losses (NLOSS), no leaks (NLEAK), and no heat exchanger (NHX) were specified. As you can see, each parameter has a default value. The parameters are listed here in SI units, but you can easily switch to English units by typing UNITS. All parameters are converted from one system to the other whenever UNITS is entered.

Fuel costs for gas, electricity, and oil may be stored in the program. Default electric rates are provided. These rates may be changed, or rates for gas or oil entered, by typing FLDATA and answering the questions. Type <u>LIST</u> <u>FLDATA</u> to see the default fuel costs:

```
list fldata

          FUEL COST

ELEC (BLOCK RATE STRUCTURE)
     ANNUAL INFLATION RATE  10.0 %
     BLOCK                1
     COST ($/GJ)        6.0
     MAX. USE (GJ)   9999.0

TYPE FLDATA TO ENTER OR CHANGE FUEL COSTS
 ?
```

To see how the example space heating system does in Ottawa, Ontario: -- type RUN. If you want to run an analysis for another location, use RUN followed by a location number. (Location numbers for the data base supplied with the program are given in Appendix B.)

Here are the performance results for the default system in Ottawa:

```
?
run


****************   FCHART  ANALYSIS   (VERSION 4.1)  *****************
 OTTAWA INT'L   ONT      LATITUDE 45.3

                          THERMAL PERFORMANCE
           HT         TA   SHLOAD       QU      QLOSS     DELTE   FNP
          (GJ)   (DEG-C)  (GJ)        (GJ)     (GJ)      (GJ)
    JAN   16.99   -10.9    21.36       6.06     0.05      0.08  0.28
    FEB   20.60    -9.5    18.49       7.72     0.07     -0.03  0.42
    MAR   27.33    -3.1    15.54      10.71     0.14      0.15  0.67
    APR   26.09     5.6     8.81       9.38     0.40      0.32  0.98
    MAY   28.94    12.4     4.30       6.21     1.08      0.83  1.00
    JUN   28.88    18.2     1.05       2.66     1.56      0.05  1.00
    JUL   30.51    20.7     0.24       1.85     1.61      0.0   1.00
    AUG   28.64    19.3     0.67       2.28     1.61      0.0   1.00
    SEP   23.81    14.6     2.92       3.86     1.34     -0.40  1.00
    OCT   19.14     8.7     6.89       6.36     0.47     -1.00  1.00
    NOV   10.72     1.4    11.86       3.96     0.04      0.06  0.33
    DEC   12.16    -7.7    18.91       4.19     0.01     -0.06  0.22
    YR   273.83     5.8   111.03      65.23     8.37     -0.00  0.51

                       PURCHASED ENERGY SUMMARY

                        GAS      ELECTRIC      OIL       TOTAL
       USE (GJ)         0.0        54.18       0.0        54.18
       COST ($)         0.0       325.07       0.0       325.07

           LIFE CYCLE COST ANALYSIS OF CURRENT SYSTEM

       INITIAL COST OF SYSTEM          $     6000.
       DOWN PAYMENT                    $      600.
       TOTAL TAX CREDITS               $     3840.
       ANNUAL MORTGAGE PAYMENT         $      550.  FOR 20 YEARS

                         UNDISCOUNTED   ANNUALIZED   PRESENT WORTH
      ENERGY COST           18618          734          7207
      TOTAL  COST           29495         1059         10393
```

The thermal analysis output table you get depends on which components you have included in your system. The following abbreviations are used to identify the monthly and yearly totals or averages in the output tables:

HT - total solar radiation incident upon aperture of collector
TA - average ambient temperature
SHLOAD - total space heating load
HWLOAD - total water heating load (including auxiliary tank losses)
LOAD - total load
QU - total useful energy gain of collector
QLOSS - total energy loss from storage
DELTE - total change in internal energy of storage
FNP - fraction of total load which is non-purchased energy
FDHW - fraction of domestic hot water load which is non-purchased energy
FW - fraction of the total load which is work input to the heat pump(s)

Now, you may wish to change some of the collector characteristics. The default collector FR-TAU-ALPHA and FR-UL are for a double-glazed collector with a black absorber. Typical values for a single-glazed collector with a selective surface absorber might be an FR-TAU-ALPHA of 0.75 and an FR-UL of 4.5. To see how 45 square meters of this alternative collector would perform, change parameter C1 to 45, C2 to 4.5, C3 to 0.75 and C6 to 1. Do this by typing

```
c1=45 c2=4.5 c3=0.75 c6=1
```

You may do this on one input line, or several. Also, the comma's and equal signs are optional. Verify these changes by typing <u>LIST COLL</u> :

```
 ?
list coll

COLLECTOR PARAMETERS                                      45.00 M2
 C1. COLLECTOR AREA ...................................    4.50 W/M2-DEG C
 C2. FR-UL PRODUCT ....................................    0.75
 C3. FR-TAU-ALPHA (NORMAL INCIDENCE) ..................    1.00
 C6. NUMBER OF COVERS (IF 0, C15 IS USED)..............    1.53
 C7. INDEX OF REFRACTION ..............................    0.04
 C8. EXTINCTION COEFFICIENT X LENGTH (KL)..............    0.0
 C9. INC. ANGLE MOD. CONSTANT (IF 0, C6-C8 USED).....     55.00 W/M2-DEG C
 C10. COLLECTOR FLOW RATE * SPECIFIC HEAT/AREA ......     43.00 DEGREES
 C12. COLLECTOR SLOPE ...............................      0.0  DEGREES
 C13. COLLECTOR AZIMUTH .............................      0.20
 C14. GROUND REFLECTANCE ............................
 C15. INCIDENCE ANGLE MODIFIERS (10,20,30,'40,50,60,70,80 DEG.)
        1.00  0.99  0.98  0.95  0.90  0.80  0.63  0.37
```

You may have noticed that some parameter numbers, such as C5, do not appear to be used. In fact, C5 is a collector parameter (CPC collector acceptance angle) but it is not related to the analysis of the current system. If you type LIST ALL before answering any system questions (or immediately after using QUICK or FORGET), you will get a list of all parameters for all systems.

An output title may be added easily using the TITLE command. You can title this run "alternative system" by typing the following

```
?
title alternative system
```

This title will then appear at the top of every printout of results until you change it. You can eliminate your title by entering a "blank" title. Now run by typing RUN. These are the performance results for the alternative system.

```
?
run

****************   FCHART  ANALYSIS   (VERSION 4.1)  *****************
 ALTERNATIVE SYSTEM
 OTTAWA INT'L   ONT     LATITUDE 45.3

                         THERMAL PERFORMANCE

          HT       TA    SHLOAD      QU      QLOSS     DELTE   FNF
         (GJ)  (DEG-C)  (GJ)       (GJ)     (GJ)      (GJ)
   JAN  15.29   -10.9    21.36      5.96     0.04      0.07 0.27
   FEB  18.54    -9.5    18.49      7.62     0.06     -0.03 0.41
   MAR  24.60    -3.1    15.54     10.59     0.13      0.13 0.67
   APR  23.49     5.6     8.81      9.30     0.37      0.29 0.98
   MAY  26.05    12.4     4.30      6.09     1.02      0.77 1.00
   JUN  25.99    18.2     1.05      2.52     1.46      0.02 1.00
   JUL  27.46    20.7     0.24      1.74     1.51      0.0  1.00
   AUG  25.78    19.3     0.67      2.17     1.51      0.0  1.00
   SEP  21.43    14.6     2.92      3.83     1.26     -0.35 1.00
   OCT  17.23     8.7     6.89      6.40     0.42     -0.91 1.00
   NOV   9.65     1.4    11.86      3.91     0.03      0.06 0.32
   DEC  10.94    -7.7    18.91      4.13     0.01     -0.06 0.22
   YR  246.45     5.8   111.03     64.26     7.80     -0.00 0.51

                    PURCHASED ENERGY SUMMARY

                       GAS     ELECTRIC    OIL      TOTAL
       USE  (GJ)       0.0      54.57      0.0      54.57
       COST  ($)       0.0     327.45      0.0     327.45

            LIFE CYCLE COST ANALYSIS OF CURRENT SYSTEM

      INITIAL COST OF SYSTEM           $    6000.
      DOWN PAYMENT                     $     600.
      TOTAL TAX CREDITS                $    3840.
      ANNUAL MORTGAGE PAYMENT          $     550. FOR 20 YEARS

                      UNDISCOUNTED   ANNUALIZED   PRESENT WORTH
      ENERGY COST         18753          739          7258
      TOTAL  COST         29632         1064         10446
?
```

At this point you may be interested in exploring some of the other features of FCHART. HELP will give you some ideas.

```
help
     TYPE IN PROGRAM COMMAND OR PARAMETER NAME AND NEW VALUE. USE THE
   FOLLOWING COMMANDS FOR MORE INFORMATION :
        LIST COMMANDS - TO GET THE LIST OF COMMANDS
        LIST ALL - TO LIST ALL PARAMETERS
        LIST PGROUPS - TO LIST THE PARAMETER GROUP (COMPONENT) NAMES
        EXPLAIN - TO GET A SHORT EXPLANATION OF EACH COMMAND
 ?
explain
   CHANGE - ALTER DATA OR SYSTEM DESCRIPTION
   CITIES - SELECT WEATHER DATA FOR UP TO 10 CITIES
   DONE   - USER DONE WITH FCHART
   ECON   - ECONOMIC ANALYSIS DESIRED
   ENTER  - ENTER WEATHER DATA FOR NEW LOCATION
   EXPLAIN- EXPLAIN ALL COMMANDS OR COMMAND SPECIFIED
   FLDATA - ENTER FUEL COST DATA.
   FORGET - FORGET SYSTEM DESCRIPTION AND BEGIN ASKING QUESTIONS
   GET    - READ SYSTEM INFORMATION OR DATA FROM FILE
   HELP   - PROVIDE INSTRUCTIONS OR ASSISTANCE
   HPDATA - ENTER HEAT PUMP PERFORMANCE DATA
   KEEP   - WRITE SYSTEM INFORMATION OR DATA TO STORAGE FILE
   LIST   - LIST SYSTEM DESCRIPTION, PARAMETERS, WEATHER DATA, ETC.
   LONG   - ASK LONG SYSTEM DESCRIPTION QUESTIONS
   LOOP   - RUN SEVERAL ANALYSES VARYING PARAMETER GIVEN
   NOECON - NO ECONOMIC ANALYSIS
   OPDATA - ENTER DATA FOR LOOPS AND OPTIMIZATION
   OPTIMZ - OPTIMIZE SYSTEM WITH RESPECT TO GIVEN PARAMETER
   PICTURE- DRAW SYSTEM SCHEMATIC
   QUICK  - ENTER QUICK SYSTEM DESCRIPTION
   RESET  - RESET PARAMETERS TO DEFAULT VALUES
   RUN    - RUN ANALYSIS OF SYSTEM FOR SPECIFIED LOCATION
   SHORT  - ASK SHORT SYSTEM DESCRIPTION QUESTIONS
   TITLE  - PRINT USER-SUPPLIED TITLE AT TOP OF OUTPUT TABLES
   UNITS  - CHANGE FROM ENGLISH UNITS TO SI, OR VICE VERSA

 TYPE EXPLAIN FOLLOWED BY ANY COMMAND NAME FOR MORE INFORMATION
 ?
```

If you want to switch from a storage tank to a rock bed, for example, use CHANGE STORE. Use EXPLAIN CHANGE for more information. Also, you can "start over" by typing FORGET and RESET, or get more detailed information on any other command using EXPLAIN followed by a command name. Good luck !

SECTION 2 - USERS GUIDE

CHAPTER 3

SYSTEMS AND SYSTEM DESCRIPTION

FCHART is useful for predicting the long-term performance of a variety of systems. Each system is described by a series of "keywords". For example, PROC FPLATE specifies a particular type of process heating system with a flat-plate collector. This chapter outlines the kinds of systems FCHART may be used for and explains the program commands and keywords used to describe each system. Commands to produce a schematic illustration or list of keywords corresponding to the current system and the methods for changing from one system to another are also presented.

3.1 Systems

3.1.1 Process Heating

A schematic diagram of the type of process heating system FCHART considers is shown in Figure 3.1. Solar energy is collected by a flat-plate, CPC, or imaging collector whenever its outlet temperature is greater than the inlet temperature. CPC collectors are assumed to have fixed aperatures with east-west axis orientations. Imaging collectors can be single-axis or two-axis trackers. A heat exchanger may be included between the collector and the storage tank to allow different working fluids. In addition, heat losses from collector pipes or ducts and duct leaks (if air is the collector working fluid) may be considered. Energy is stored as sensible heat in a water storage tank. The tank is assumed to be pressurized such that there is no energy boil-off. Heat is supplied from storage to the load by a delivery device if there is an energy demand and if the storage temperature is greater than a user specified minimum useful temperature. The delivery device may be a heat exchanger or a heat pump. If a heat pump is chosen, direct solar heating occurs across a heat exchanger whenever the storage temperature is greater than a minimum bypass temperature. The direct solar heating mode can be eliminated by specifying a large bypass temperature. Inlet conditions to the load side of the delivery device (T_{Li} and $\dot{m}_{Li}$ in figure 3.1) are assumed to be constants when the load occurs. The load is an energy demand occurring 7 days per week over a user specified number of hours per day. Auxiliary energy is added by conventional furnace (electric, gas,or oil) if the delivery device cannot meet the load.

3.1.2 Liquid-Based Space and Water Heating

A schematic of the liquid-based space and water heating system which FCHART considers is shown in Figure 3.2. A flat-plate, CPC, or imaging collector operates whenever there is a net useful

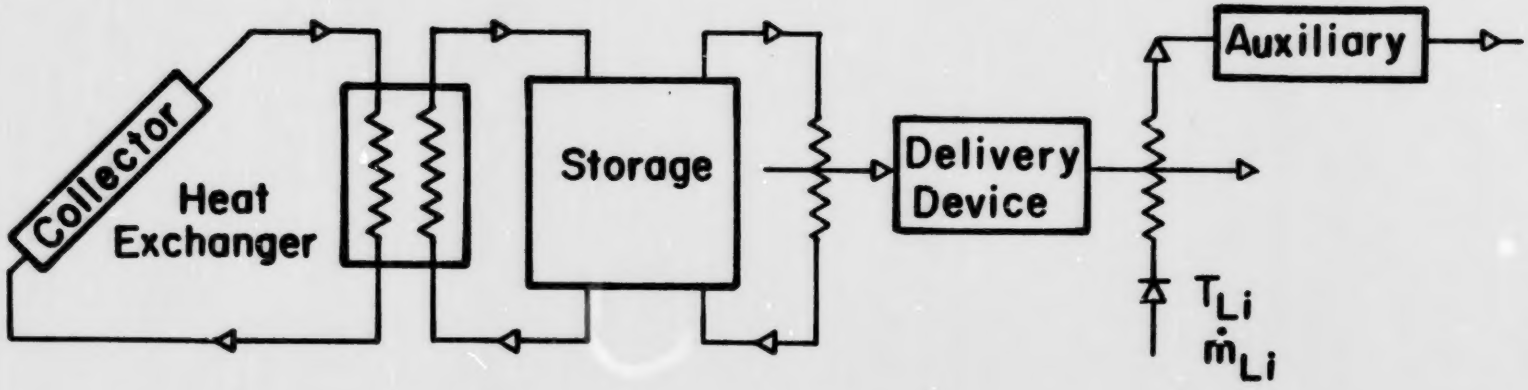

Collector
Heat
Exchanger
Storage
Delivery
Device
Auxiliary
T_{Li}
$\dot{m}_{Li}$

Figure 3.1. Schematic of a Closed-Loop Process Heating System

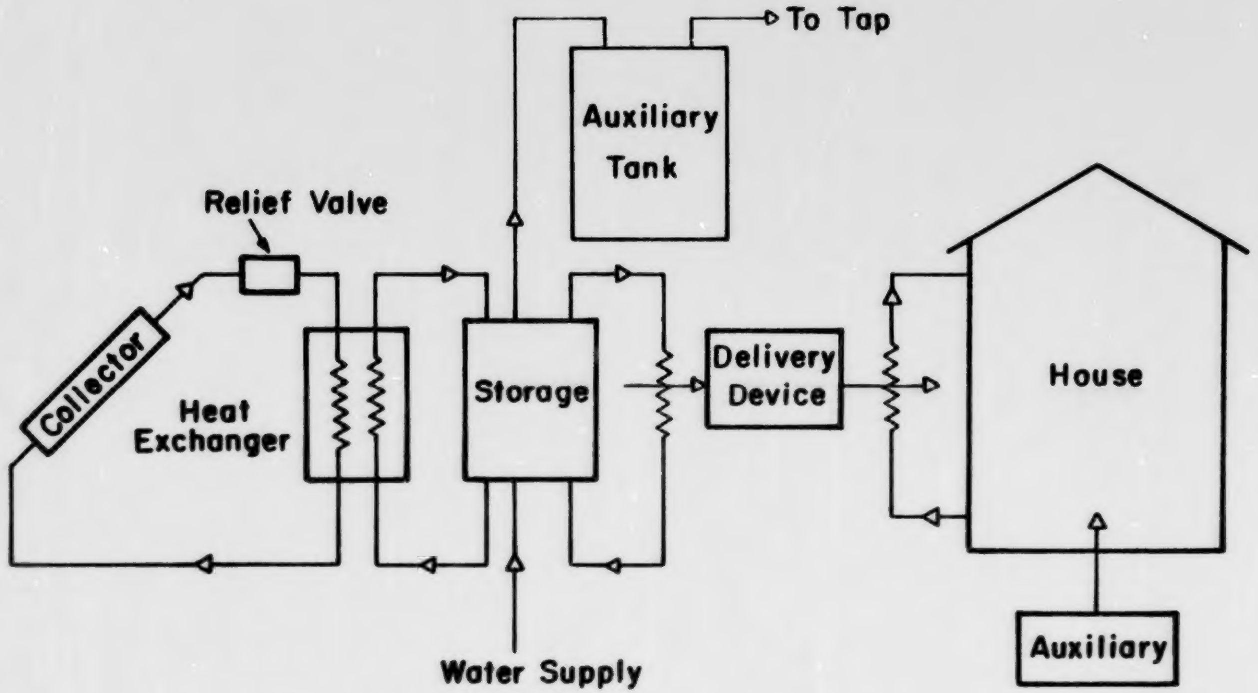

To Tap
Auxiliary Tank
Relief Valve
Collector
Heat Exchanger
Storage
Delivery Device
House
Auxiliary
Water Supply

Figure 3.2. Schematic of a Liquid-Based Space and Water Heating System

energy gain. If a heat exchanger is included between the collector and the storage tank, the collector working fluid may be air and duct leaks can occur. In addition, heat losses from collector pipes or ducts may be considered. A relief valve is located on a water storage tank to prevent the temperature from exceeding 100 degrees centigrade. Heat is supplied from storage to the heated space by a delivery device if there is an energy demand and if the storage temperature is greater than a user specified minimum useful temperature. An "ideal" controller is assumed which maintains a fixed room temperature. The delivery device may be a heat exchanger or a heat pump. If a heat pump is chosen, direct solar heating occurs across a heat exchanger whenever the storage temperature is greater than a minimum bypass temperature. Auxiliary energy is added to the heated space by a heat pump and/or conventional furnace if the delivery device cannot meet the load. The storage tank also acts as preheater for the domestic hot water system. Additional energy, if required, is added by conventional water heater to maintain the desired set temperature. A mixing valve prevents the auxiliary tank outlet temperature from exceeding the desired set temperature. The water mains temperature, set temperature, and daily usage are assumed to be constants for any one month but may vary by month. If only space heating is to be considered, then the conventional water heater, mixing valve, and associated piping and controls are not included. For DHW only systems, the building, delivery device, and relief valve are not pertinent.

3.1.3 Air-Based Space and Water Heating

A schematic of the air-based space and water heating system for which FCHART is applicable appears in figure 3.3. Energy collection is accomplished by use of a flat-plate collector. Duct or pipe losses and duct leaks may be considered between the collector and storage. Storage is a rock bed or a phase change device. Energy is delivered to the heated space from storage or the collectors as a result of air flow into the space. System operation is characterized by the following three modes:

1) Collector to load - energy is demanded by the heated space and the collector outlet temperature is greater than the room temperature
2) Collector to storage - the collector outlet temperature is greater than the temperature at the bottom of storage and there is no space heating load
3) Storage to load - no collection is available, energy is demanded by the heated space, and the temperature in the top of storage is greater than the room temperature.

In modes 1 and 3, auxiliary energy from a heat pump and/or conventional furnace may supplement the solar contribution. Energy is supplied for domestic hot water by heat exchange from the hot air exiting the collector to a preheat tank. Additional energy, if required, is added by a conventional water heater to maintain the desired set temperature. The water mains temperature, set temper-

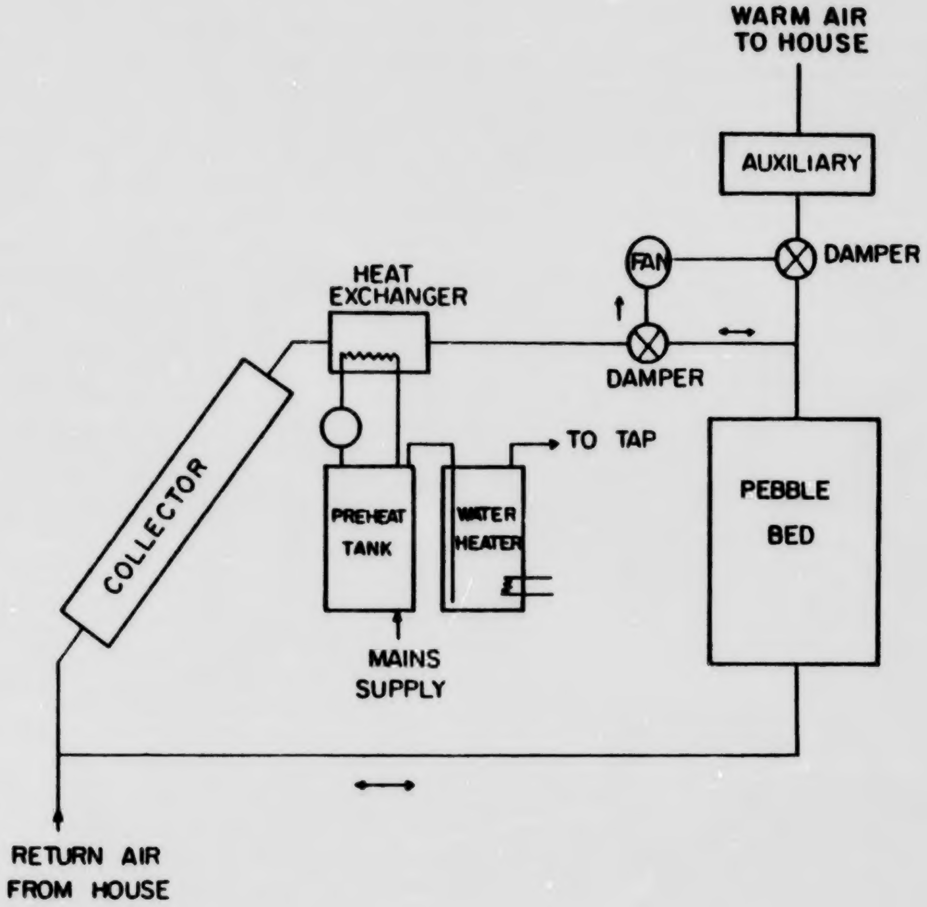

WARM AIR
TO HOUSE
AUXILIARY
FAN
DAMPER
HEAT
EXCHANGER
DAMPER
TO TAP
COLLECTOR
PREHEAT
TANK
WATER
HEATER
PEBBLE
BED
MAINS
SUPPLY
RETURN AIR
FROM HOUSE

Figure 3.3. Schematic of an Air-Based Space and Water Heating System

ature, and daily usage are assumed to be constants for any one month but may vary by month. The preheat tank, conventional water heater, and associated piping and controls are not included for a space heating only system. Without DHW, it is possible to specify a heat exchanger between the collector and storage device to allow different working fluids. Without space heating, a liquid-based DHW system results. Whenever air is the collector working fluid and water heating is considered, a heat exchanger between the collector and the pre-heat tank must be specified as a transfer device.

3.2 FCHART System Description

The first step in using FCHART is to select components and analysis options appropriate for the system under consideration. In the example presented in Section I, a liquid-based space heating system was described by answering a series of questions. The answers given to the questions were

```
SPACE     ACTIVE    FPLATE    NLOSS     NLEAK     NHX
LIQ       HX        UA        FUEL      ECON
```

Each of these keywords refers to one of the eight system sections named in the illustration below.

```
forget
  WOULD YOU LIKE INSTRUCTIONS (YES,NO,QUICK) ?
picture


        SYSTEM TYPE :                                        **********
                                                             *  AUX   *
                                                             **********
                                                                 I
**********   **********   **********   **********   **********
* COLLEC *-->* TRANS  *-->* STORE  *-->* DELIV  *-->*  LOAD  *
**********   **********   **********   **********   **********


                                   ECONOMICS :
```

The keywords SPACE and ACTIVE describe a system type, active solar space heating, while FPLATE specifies a flat-plate collector. Three keywords, NLOSS, NLEAK and NHX, for no collector pipe or duct losses, no leaks and no heat exchanger, are used to describe the collector-storage transfer loop. Some of the eight system sections

```
TYPE          COLLECTOR   TRANSFER    STORAGE
DELIVERY      LOAD        AUXILIARY   ECONOMICS
```

are described completely by a single keyword while others require two or more. In some cases, the number of keywords required varies. For a process heating system, PROC describes SYSTEM TYPE completely. In the description of an active solar space heating system pictured below, the two words which appear adjacent to the heading SYSTEM TYPE are required.

```
                                                         **********
        SYSTEM TYPE : SPACE                              *  AUX   * FUEL
                      ACTIVE                             **********
                                                             I
**********   **********   **********   **********   **********
* COLLEC *-->* TRANS  *-->* STORE  *-->* DELIV  *-->*  LOAD  *
**********   **********   **********   **********   **********
  FPLATE       NLOSS        LIQ          HX             UA
               NLEAK        TANK
               NHX                   ECONOMICS : ECON
```

3.2.1 Answering System Description Questions

The easiest way to describe a system is to answer the questions FCHART asks. Whenever you have not described a system completely, the program will ask you a question. If you choose to type in a program command (e.g. PICTURE) instead of answering a question, the question will be asked again after the command is executed. If you are not sure how to answer a question, type HELP. FCHART will then list the possible responses and give a brief explanation of each. Descriptions of each response keyword are also given below.

There are two formats for each question, short and long. If you ask for instructions when you start the program, or after typing FORGET, you will get long questions. Otherwise, you will be asked short questions. Each long question ends by giving the possible responses in parentheses while short question consist entirely of a list of responses. To switch from short questions to long questions, type LONG. To switch back, use SHORT. The QUICK command (described later) also switchs you to short questions.

```
SYSTEM TYPE
     PROC - PROCESS HEATING
     SPACE - SPACE HEATING (ONLY) SYSTEM
     SDHW - COMBINED SPACE AND DOMESTIC WATER HEATING
     DHW - DOMESTIC HOT WATER (ONLY) SYSTEM
     ACTIVE - ACTIVE SOLAR SYSTEM USED FOR SPACE HEATING
     NOACTIVE - NO ACTIVE SOLAR SPACE HEATING SYSTEM
          (ANSWER NOACTIVE FOR HEAT PUMP ONLY SYSTEM)
COLLECTOR
     FPLATE - FLATE PLATE SOLAR COLLECTOR
     CPC - COMPOUND PARABOLIC CONCENTRATING COLLECTOR
     IMAGE - TRACKED IMAGING COLLECTOR
TRANSFER (COLLECTOR TO STORAGE)
     LOSS  - FOR FCHART TO CALCULATE PIPE OR DUCT HEAT LOSSES
     NLOSS - TO IGNORE COLLECTOR PIPE OR DUCT LOSSES
     LEAK  - TO CONSIDER COLLECTOR DUCT AIR LEAKS
     NLEAK - IF YOU HAVE A LIQUID COLLECTOR OR WISH TO
             IGNORE THE EFFECTS OF DUCT AIR LEAKS
     HX  - TO ACCOUNT FOR COLLECTOR-STORE HEAT EXCHANGER
     NHX - IF YOU DO NOT WANT COLLECTOR-STORE HX CALCULATIONS
STORAGE
     AIR - FOR AIR-BASED STORAGE DEVICE
     LIQ - FOR LIQUID BASED STORAGE UNIT
     TANK - LIQUID STORAGE TANK
     ROCK - ROCK BED HEAT STORAGE
     PCES - PHASE CHANGE ENERGY STORAGE
DELIVERY DEVICE (STORAGE TO LOAD)
     HX - HEAT DELIVERED TO LOAD BY HEAT EXCHANGER
     HP - ENERGY SUPPLIED BY SERIES HEAT PUMP
LOAD
     INPUT - USER INPUT OF MONTHLY LOAD VALUES
     UA  - SPACE HEATING LOAD CALCULATED FROM BUILDING UA
```

```
AUXILIARY
     HP - HEAT PUMP FOR BACK UP SPACE HEATING
     FUEL - CONVENTIONAL FUEL AUXILIARY
ECONOMICS
     ECON   - IF YOU WANT AN ECONOMIC ANALYSIS OF YOUR SYSTEM
     NOECON - TO GET A THERMAL ANALYSIS ONLY
```

3.2.2 Listing Your System Description

There are two commands which may be used to see what kind of system has been described, LIST SYSTEM and PICTURE. PICTURE will give you a "schematic diagram" along with the choices you have made, as shown below.

```
picture


                                                    **********
         SYSTEM TYPE : SPACE                        *  AUX   * FUEL
                       ACTIVE                       **********
                                                        I
**********   **********   **********   **********   **********
* COLLEC *-->* TRANS  *-->* STORE  *-->* DELIV  *-->*  LOAD  *
**********   **********   **********   **********   **********
  FPLATE      NLOSS        LIQ          HX           UA
              NLEAK        TANK
              NHX                  ECONOMICS : ECON

 ?
```

specify the system you have described. Both PICTURE and LIST SYSTEM may be used before a system description is completed to see what options have been chosen thus far.

```
list system
   SYSTEM DESCRIPTION :
       SPACE     ACTIVE    FPLATE    NLOSS     NLEAK     NHX
       LIQ       HX        UA        FUEL      ECON
  ?
```

3.2.3 Quick System Description

The QUICK command may be used to enter system descriptions without being asked questions. This saves time since you do not have to wait for questions to be printed and is also useful if you run FCHART in a batch environment. To describe the system illustrated here, for example

```
pic


                                                    **********
         SYSTEM TYPE : SPACE                        *  AUX   * FUEL
                       ACTIVE                       **********
                                                        I
**********   **********   **********   **********   **********
* COLLEC *-->* TRANS  *-->* STORE  *-->* DELIV  *-->*  LOAD  *
**********   **********   **********   **********   **********
  FPLATE       NLOSS        AIR                        UA
               NLEAK        ROCK
               NHX                  ECONOMICS : ECON
```

all you need to do is type QUICK followed by the keywords necessary to describe the system, i.e.

```
     TYPE IN SYSTEM DESCRIPTION KEYWORDS, E.G. SPACE, ACTIVE, FPLATE ...
quick space active fplate nloss nleak nhx air rock ua fuel econ

   SYSTEM DESCRIPTION COMPLETE
```

The exact keywords used to define a system are always given by LIST SYSTEM; PICTURE sometimes includes extra keywords which are inferred by FCHART. Note the order: SYSTEM TYPE first, next left to right from COLLECTOR to LOAD, then AUXILIARY and ECONOMICS. The keywords may be typed in on as many lines as desired. When you come to the end of a line, or forget which keyword comes next, just hit the carriage return key and FCHART will prompt you with a short question. Table 1 on the next page summarizes the available options and the proper order for typing them in.

Although the QUICK command is available, it is not really necessary to use QUICK to describe a system quickly. Whenever you know which question will be asked next, you may enter the answer before the question is asked. This keeps FCHART from having to ask the question; the program goes on to the next question. Thus QUICK is essentially equivalent to FORGET (erase the current system description and begin asking questions) followed by NO (no instructions desired).

Table 1
Quick System Description

SYSTEM TYPE
- 1) Select basic system type
  - PROC - PROCESS HEATING
  - SPACE - SPACE HEATING (ONLY) SYSTEM
  - SDHW - COMBINED SPACE AND DOMESTIC WATER HEATING
  - DHW - DOMESTIC HOT WATER (ONLY) SYSTEM
- 2) If SPACE or SDHW, specify type of space heating
  - ACTIVE - ACTIVE SOLAR SYSTEM USED FOR SPACE HEATING
  - NOACTIVE - NO ACTIVE SOLAR SPACE HEATING SYSTEM (ANSWER NOACTIVE FOR HEAT PUMP ONLY SYSTEM)

COLLECTOR
- 1) Pick a collector
  - FPLATE - FLATE PLATE SOLAR COLLECTOR
  - CPC - COMPOUND PARABOLIC CONCENTRATING COLLECTOR
  - IMAGE - TRACKED IMAGING COLLECTOR

TRANSFER (Collector to Storage)
- 1) Choose three transfer options, one from each pair
  - LOSS - FOR FCHART TO CALCULATE PIPE OR DUCT HEAT LOSSES
  - NLOSS - TO IGNORE COLLECTOR PIPE OR DUCT LOSSES
  - LEAK - TO CONSIDER COLLECTOR DUCT AIR LEAKS
  - NLEAK - IF YOU HAVE A LIQUID COLLECTOR OR WISH TO IGNORE THE EFFECTS OF DUCT AIR LEAKS
  - HX - TO ACCOUNT FOR COLLECTOR-STORE HEAT EXCHANGER
  - NHX - IF YOU DO NOT WANT COLLECTOR-STORE HX CALCULATIONS

STORAGE
- 1) If (SPACE or SDHW) and ACTIVE with FPLATE, pick working fluid
  - AIR - FOR AIR-BASED STORAGE DEVICE
  - LIQ - FOR LIQUID BASED STORAGE UNIT
- 2) If AIR chosen, select a device
  - ROCK - ROCK BED HEAT STORAGE
  - PCES - PHASE CHANGE ENERGY STORAGE

DELIVERY DEVICE (Storage to Load)
- 1) IF PROC or Liquid-Based SPACE, choose one
  - HX - HEAT DELIVERED TO LOAD BY HEAT EXCHANGER
  - HP - ENERGY SUPPLIED BY SERIES HEAT PUMP

LOAD
- 1) For SPACE or SDHW, pick a space heating load method
  - INPUT - USER INPUT OF MONTHLY LOAD VALUES
  - UA - SPACE HEATING LOAD CALCULATED FROM BUILDING UA

AUXILIARY
- 1) For SPACE or SDHW, select a space heating auxiliary
  - HP - HEAT PUMP FOR BACK UP SPACE HEATING
  - FUEL - CONVENTIONAL FUEL AUXILIARY

ECONOMICS
- 1) Decide whether or not you want economics
  - ECON - IF YOU WANT AN ECONOMIC ANALYSIS OF YOUR SYSTEM
  - NOECON - TO GET A THERMAL ANALYSIS ONLY

3.2.4 Changing System Descriptions

You may change any part of your system description using the CHANGE command. Since there are eight sections to the system description, there are eight CHANGE options for changing systems:

```
CHANGE TYPE
CHANGE COLLECTOR
CHANGE TRANSFER
CHANGE STORE
CHANGE DELIVERY
CHANGE LOAD
CHANGE AUXILIARY
CHANGE ECONOMICS
```

As with all FCHART input, each word may be abbreviated by two or three letters, e.g. CH COL for CHANGE COLLECTOR.

The effect of each of the above commands is to erase a section of the system description and begin asking questions about that section of the system. If you enter CHANGE TYPE, for example, you will be asked to select PROC, SPACE, SDHW, or DHW. Then, if you answer SPACE or SDHW, you will be asked whether space heating is by active or passive means. When you have answered all the required questions, you will get the message SYSTEM DESCRIPTION COMPLETE.

FCHART always looks to see if you have answered a question before asking it. If you type

```
CHANGE TYPE SPACE ACTIVE
```

for example, you will not be asked the questions concerning system type. This is convenient if you remember which keywords correspond to the option you want. If you forget, you can always wait for the questions to be printed. The "Quick System Description Guide" given in Table 1 may also be helpful.

In some cases, changing one part of the system will require changes in other parts of the system description. For example, air-based space heating systems have no delivery device option; air ducts are assumed. Liquid-based space heating systems, on the other hand, require either a heat exchanger or a heat pump to be specified. If you change storage from air to liquid, then you will need to select either HX or HP. The program will always ask you for whatever information it requires.

The commands ECON and NOECON may also be used to change the economics specification. To receive an economic analysis with each thermal analysis, type

```
ECON
```

This is equivalent to CHANGE ECON ECON but much easier to type in. If you prefer not to have an economic analysis, you can use the command

```
NOECON
```

This is equivalent to CHANGE ECON NOECON.

CHAPTER 4

PARAMETERS

4.1 Parameter Groups

The performance of any system depends upon the choice of components and the characteristics of each component. Once components have been selected (Chapter 3), their characteristic must be specified. This is done by setting "parameters" to appropriate numerical values. Every component (collector, transfer loop, storage, etc.) has an associated list of parameters which describe its operating characteristics.

There are seven parameter groups:

```
COLLECTOR   TRANSFER    STORAGE     DELIVERY
LOAD        AUXILIARY   ECONOMICS
```

The parameters included in each group may depend upon which type of component or analysis option has been chosen. Collector concentration ratio, for example, is a collector parameter only if a CPC or imaging collector is used.

There are several LIST commands which are related to parameters and parameter groups. They are:

LIST ALL - List all parameters for current system.

LIST PGROUPS - List the parameter group names, i.e. COLLECTOR, TRANSFER, STORAGE, etc.

LIST "group name" - List all parameters in the group specified, e.g. LIST LOAD.

LIST "parameter name" - List the value of the parameter named, e.g. LIST C1

If you type LIST ALL before describing a system, you will get the list of all parameters for all systems.

4.2 Default Values and Units

Every parameter has a default value. This provides a built-in example system which is useful for the beginning user and for isolating problems related to variations between computer systems. (A list of all default parameters in FCHART is given in Appendix A.) The default values are not intended to correspond to the "best" system of any type for any location. All paramters may be reset to their default values using the command RESET.

FCHART can manipulate parameters and perform calculations in either the SI or English system of units. The units for each parameter in the unit system being used are listed to the right of the parameter values in any parameter listing. To switch from one system of units to the other, type UNITS. All parameters will then be converted and a message will be printed telling which system of units is then in effect.

4.3 Changing Parameter Values

Parameter names consist of a single letter abbreviating the parameter group followed by a number. For instance the first collector parameter, collector area, is "named" C1. To change the value of any parameter, type the parameter name followed by the value you want. An equals sign ("=") may be inserted if you desire; either

```
c1=50    or    c1 50
```

will set collector area to 50. Some parameters may be varied by month. These parameters, described in more detail below, may be set as above if a single value for the entire year of analysis is desired.

4.4 Varying Parameters by Month

In order to determine the long-term average performance of any system, FCHART does a series of twelve monthly analyses. It some cases, system performance may be enhanced or the accuracy of the analysis increased by allowing parameters such as collector slope or ground reflectance to vary from month to month. Seven parameters have been indetified as those which users of FCHART are most likely to want to vary. These are

C12. Collector Slope
C13. Collector Azimuth Angle
C14. Ground Reflectance
L3. Hot Water Use
L4. Hot Water Set Temperature
L5. Water Mains Temperature
L6. Total Process or Space Heating Load

When the same value is to be used for all twelve months of the analysis, the above parameters may be treated just like all other parameters, i.e.

```
c12=45
```

will set the collector slope to 45 degrees. If more than one value is desired, twelve monthly values must be supplied. To set the collector slope to 40 degrees for April through September and 50 degrees for October through May, type

```
c12=50,50,50,40,40,40,40,40,40,50,50,50
```

The equals sign and the comma's are optional. When you enter

```
list c12
```

you will then get

```
C12. COLLECTOR SLOPE ..................................
      50.00    50.00    50.00    40.00    40.00    40.00
      40.00    40.00    40.00    50.00    50.00    50.00          DEGREES
```

The monthly values are listed January to June from left to right on the first line and July to December from left to right on the second.

4.5 Parameter Descriptions

Brief descriptions of each parameter are given below. The analysis method descriptions in Section III of this manual provide further information on how each parameter is used.

4.5.1 Collector Parameters

C1. COLLECTOR AREA ....

The total collector aperture area used in your system. The same area (gross or net) as used in determining C2 and C3 should be supplied here.

C2. FR-UL PRODUCT ....

If collector performance data is plotted as collector efficiency versus (Tin - Tamb)/I, a straight line will usually fit the data points well. FR-UL, the product of the heat removal factor FR and the overall loss coefficient UL, is the negative of the slope of this line. A collector test procedure for determining FR-UL and FR-TAU-ALPHA is described in ASHRAE Standard 93-77. FR-UL is assumed to be based on aperture area.

If the data is plotted with either the outlet temperature or the average temperature in place of inlet temperature, then it is necessary to calculate FR-UL and FR-TAU-ALPHA (C2 and C3) as described in Chapter 10 of the third section of this manual. The data used to construct the plot of efficiency vs. (Tin-Tamb)/I must be taken using the same collector flow rate as is expected in the installation. For liquid heating solar collectors, data taken at different flowrates may be modified as outlined in Chapter 10.

C3. FR-TAU-ALPHA (NORMAL INCIDENCE) ....

The collector heat removal factor FR times the transmittance-absorptance product TAU-ALPHA (also called optical efficiency) is the y-intercept of the straight line efficiency plot described above.

C4. CONCENTRATION RATIO ....

The ratio of collector aperture area to absorber area. Used for CPC's and imaging concentrators only.

C5. CPC ACCEPTANCE HALF-ANGLE ....

CPC collectors accept all radiation incident within the acceptance half-angle of the optical axis.

C6. NUMBER OF COVERS (IF 0, C15 IS USED)...................

Number of transparent covers over the collector absorber. Parameters C6-C8 are used to estimate incidence angle effects for flat plate collectors if C9 is set to zero and C6 is greater than zero. If C6 is set equal to or less than zero, then parameter C15 is used.

C7. INDEX OF REFRACTION ....

For glass covers, use 1.526.

C8. EXTINCTION COEFFICIENT * LENGTH ....

Product of the extinction coefficient of the cover material and the thickness of each cover. See Solar Engineering of Thermal Processes (10).

C9. INC. ANGLE MOD. CONSTANT (IF 0,C6-C8 USED)................

The incidence angle modifier K(t) is the transmittance-absorptance product at incidence angle t divided by the transmittance-absorptance product at normal incidence. Parameter C9, the incidence angle modifier constant, is the number b which provides the best fit in the equation

$$K(t) = 1. - b(1./\cos(t) - 1.)$$

The constant b can be determined experimentally for flat-plate collectors as described in ASHRAE Standard 93-77. If a value of b of zero is specified, parameters C6-C8 are used to consider incidence angle effects. If C6 is set equal to or less than zero, then C15 is used regardless of the value of C9.

C10. COLLECTOR FLOW RATE * SPECIFIC HEAT/AREA ......

Collector capacitance rate per unit area. In air-based systems, this parameter is used to correct for variations in storage stratification. In systems with collector-storage heat exchangers, it is used to account for heat exchanger effects.

C11. TRACKING AXIS (1=EW, 2=NS, 3=2-AXIS) ....

Three tracking modes are available for imaging collectors: east-west axis, north-south axis, and dual-axis tracking.

C12. COLLECTOR SLOPE ....

The angle between the plane of the collector aperture and the ground (horizontal) (may have 12 monthly values).

C13. COLLECTOR AZIMUTH ....

The deviation of the normal to the collector surface from the local meridian; the zero point directly facing the equator, west positive, and east negative. (May have 12 monthly values.)

C14. GROUND REFLECTANCE ....

Reflectance of horizontal surface in front of collector. This is used to estimate the total solar radiation incident on flat-plate collectors (may have 12 monthly values).

C15. INCIDENCE ANGLE MODIFIERS (10,20,30,40,50,60,70,80 DEGREES)

Eight values of incidence angle modifiers for 10-80 degrees. At 0 and 90 degrees the modifiers are 1 and 0, respectively. For flat-plate collectors, these values are only used if C6 is set equal to or less than zero. For CPC's or single-axis tracking concentrators, these are the incidence angle modifiers for the plane which passes through the collector axis and is normal to the collector aperture.

4.5.2 Collector-Store Transfer Parameters

T1. EPS-CMIN OF COLLECTOR-STORE HX/COLLECTOR AREA ..

Effectiveness of collector-store heat exchanger times the minimum of the two capacitance rates (mass flow rate times specific heat) through the heat exchanger, divided by collector area. In air-based combined space and water heating systems, this parameter refers to the heat exchanger from the collector outlet duct to the water preheat tank.

T2. UA OF COLLECTOR INLET PIPE OR DUCT ....

Overall loss coefficient U of inlet pipe or duct multiplied by surface area A.

T3. UA OF COLLECTOR OUTLET PIPE OR DUCT ....

Overall loss coefficient U of outlet pipe or duct multiplied by surface area A.

T4. COLLECTOR DUCT LEAK RATE (PER CENT) ....

Percent of collector outlet duct flowrate which is leakage. The collector is assumed to be under negative pressure, i.e. all leaks are into the ducts rather than out.

T5. DUCT LEAK LOCATION (1=INLET,2=OUTLET,3=BOTH) ...

The total leakage may be assumed to occur in the inlet duct, the outlet duct, or may be evenly distributed between the two ducts.

4.5.3 Storage Unit Parameters

S1. TANK CAPACITY/COLLECTOR AREA ....

Tank energy storage capacity per unit collector area (storage mass times specific heat divided by collector area). For liquid based combined space and water heating systems, this is the capacity of the space heating tank plus the capacity of the domestic water preheat tank if one is used. When two tanks are to be accounted for, parameters S2 and S3 must be set so that the correct tank UA will be calculated. For air-based combined space and water heating, this is the capacity of both the spce heating storage medium and the domestic hot water preheat tank. In this situation, parameter S3 represents the U-value for water preheat tank ONLY.

S2. STORAGE UNIT HEIGHT/DIAMETER RATIO ....
Ratio of height of tank referred to by parameter S1 to tank diameter.

S3. HEAT LOSS COEFFICIENT ....
Overall loss coefficient of tank referred to by parameter S1.

S4. ENVIRONMENT TEMPERATURE (-1000 FOR TENV=TAMB) ..
Temperature to which tank losses occur. If -1000 is specified, the environment temperature is set equal to the average monthly ambient temperature.

S5. HOT WATER AUXILIARY TANK UA ....
Overall loss coefficient U times surface area A of hot water auxiliary tank. The auxiliary tank temperature is assumed to be the hot water set temperature (parameter L4).

S6. HOT WATER AUX TANK ENVIRONMENT TEMPERATURE .....
Temperature to which auxiliary tank losses occur.

S7. ROCK BED CAPACITY/COLLECTOR AREA ....
Energy storage capacity (mass times specific heat) of rock bed per unit collector area.

S8. PHASE CHANGE VOLUME/COLLECTOR AREA (X1000)..........
Volume of phase change unit divided by collector area times one thousand. The volume of phase change material is the phase change unit volume times one minus the void fraction (parameter S10).

S9. PHASE-CHANGE MATERIAL DENSITY ....
Density of the phase-change material used in the storage device (not the average density of the storage device).

S10. VOID FRACTION ....
Fraction of the phase-change unit volume which does not contain phase-change material.

S11. SOLID PHASE SPECIFIC HEAT ....
The specific heat of the phase change material when it is in solid phase.

S12. LIQUID PHASE SPECIFIC HEAT ....
The specific heat of the phase change material when it is in liquid phase.

S13. HEAT OF MELTING ....
Energy absorbed by melting of unit mass of phase-change material.

S14. MELTING TEMPERATURE ....
Temperature at which phase-change material melts.

4.5.4 Delivery Device Parameters

D1. EPS-CMIN OF LOAD HEAT EXCHANGER ....
Effectiveness of load heat exchanger times the minimum of the two capacitance rates (mass flow rate times specific heat) through the heat exchanger.

D2. MINIMUM TEMPERATURE FOR HX OPERATION ....
Minimum storage temperature for operation of load heat exchanger pump and fan.

D3. DELIVERY HEAT PUMP NUMBER ....
Heat pump performance data is indexed by "heat pump numbers" (see Chapter 8). This parameter is the number corresponding to the performance data for the heat pump which delivers heat from storage to the load.

D4. MINIMUM HEAT PUMP ABSORBER TEMPERATURE ....
Minimum storage temperature (heat pump absorber temperature) required for heat pump operation.

D5. HEAT PUMP BYPASS TEMPERATURE ....
Maximum storage temperature for heat pump operation. When storage is above this temperature, heat is delivered through the load heat exchanger and the heat pump is bypassed.

4.5.5 Load Parameters

L1. BUILDING UA ....
Overall building loss coefficient U times exterior surface area A. The total building load for a month is the UA times the monthly degree days (based on 18.3 deg. C. (65 deg. F.) base temperature). Degree days may be listed using LIST DATA or LIST DDAYS and entered or changed using ENTER or CHANGE.

L2. ROOM TEMPERATURE ....
The temperature of the unheated air entering the load heat exchanger.

L3. HOT WATER USE ....
Total average daily mass demand (total mass demand for month divided by number of days in month).

L4. HOT WATER SET TEMPERATURE ....
Desired temperature of heated water. This temperature is used to calculate total water heating loads and also effects the auxiliary tank heat losses (see parameter S5 description).

L5. WATER MAINS TEMPERATURE ....

Temperature of cold water supplied to water heating system.

L6. TOTAL PROCESS OR SPACE HEATING LOAD ....

Total average daily energy demand.

L7. HOURS PER DAY ....

Number of hours per day that the load operates. It is assumed that the time distribution of the load is not significant. Only the monthly capacitance rate (hourly capacitance rate times hours of operation over the month) is considered in the analysis (see Section III).

L8. LOAD RETURN TEMPERATURE ....

Load heat exchanger cold side inlet temperature; the temperature of the fluid returned from the load to the heat exchanger (Tli in Figure 1.1).

4.5.6 Auxiliary Parameters

A1. AUXILIARY FUEL TYPE (1=GAS,2=ELEC,3=OIL) ....

The type of fuel used for space heating or process heating auxiliary. Use 1 for gas auxiliary, 2 for electric, and 3 for oil. If some other fuel is used, select one of these three and enter the appropriate cost using the command FLDATA. This parameter is used for the purchased energy summary and fuel cost calculations only.

A2. AUXILIARY DEVICE EFFICIENCY ....

Average annual auxiliary device efficiency. The total fuel consumption is the total energy demand divided by the consumption efficiency.

A3. HOT WATER AUXILIARY FUEL (1=GAS,2=ELEC,3=OIL) ..

Type of fuel used for domestic water heating auxiliary. (See A1 above.)

A4. AUXILIARY WATER HEATER EFFICIENCY ....

Average annual auxiliary water heater efficiency. Fuel consumption is energy demand divided by efficiency.

A5. AUXILIARY HEAT PUMP NUMBER ....

Heat pump performance data is indexed according to "heat pump number" (see Chapter 8). Set this parameter to the number of the heat pump performance data set which corresponds to the ambient source ("auxiliary") heat pump.

4.5.7 Economic Parameters

E1. ECONOMIC OUTPUT DETAIL (1,2 OR 3) ....

Three levels of detail are available for the economic analysis output. Use 1 for short output, 2 for more complete economic indicators, and 3 for annual cash flow summaries.

E2. REFERENCE OR COMPARISON SYSTEM (1 OR 2) ....

The "economics package" can be used to determine the life cycle cost of purchasing and operating a system, or for determining costs and savings relative to some reference system. Set this parameter to 1 to get life cycle cost information ("reference system") only. When E2=2, the current system is compared against the most recently run reference system.

E3. CALCULATE RATE OF RETURN (YES=1,NO=2) ....

If E3=1, the the rate of return on the current system investment relative to the reference system can be calculated. Set parameter E3 to 2 to avoid this calculation.

E4. INCOME PRODUCING BUILDING (YES=1,2=NO) ....

Use 1 for commercial economics, 2 for residential. Commercial buildings have different federal tax credits, income tax deductions, and depreciation deductions.

E5. DEPRC: STR,LN.=1,DC.BAL.=2,SM-YR-DGT=3,NONE=4 ..

Three types of depreciation for commercial buildings are offered: straight line, declining balance, and sum of the years digits. If E5=4, depreciation is not considered.

E6. CONSIDER FEDERAL TAX CREDITS (YES=1,2=NO) ......

Set this parameter to 1 to get federal tax credits, use 2 to ignore federal tax credits.

E7. LENGTH OF ANALYSIS ....

Number of years of "life cycle". The system is assumed to be sold and any remaining mortgage paid off in the final year of the analysis.

E8. TAX CREDITABLE SYSTEM BASE COST ....

In general, some of the system costs will be eligible for tax credits and some will not. In addition, some of the costs result from purchasing components which are being OPTIMIZED or LOOPed (see Chapter 5) while the rest of the initial investment is independent of these components. This parameter should be set to the total system cost which is eligible for tax credits and which is independent of any components OPTIMIZEd or LOOPed.

E9. NON-TAX CREDITABLE SYSTEM BASE COST ....$

System cost which is not eligible for tax credits and which is independent of any components on LOOP or OPTIMIZE commands (see E8 above).

E10. ANNUAL INCREASE IN PURCHASED ENERGY DEMAND ....

Annual per cent increase in demand for purchased energy. Usually this increase is a result of dergradation in solar system performance. Warning: the purchased energy requirement after N years is (1 + E10/100)**N times the first year's requirement. If E10 is 15%, the purchased energy requirement will double in 5 years.

E11. TERM OF MORTGAGE ....
Length of mortgage (in years). If the system is financed by cash outlay, set E11 to 1 and set E12 to 100.

E12. DOWN PAYMENT (% OF ORIGINAL INVESTMENT) ....
Percent of total system cost which will be paid initially.

E13. MORTGAGE ANNUAL INTEREST RATE ....
Interest rate on mortgage.

E14. RESALE VALUE (% OF ORIGINAL INVESTMENT) ....
Cash received for resale in final year of analysis as percentage of original system cost. For commercial buildings, the cash received is assumed to be the maximum of the resale value and the value to which the investment has been depreciated.

E15. ANNUAL NOMINAL (MARKET) DISCOUNT RATE ....
The nominal discount rate is the annual rate of return of the best alternative investment. This is the real rate of return plus the general inflation rate. Since extra cash can be used to pay back the mortgage, the minimum rate of return (discount rate) is the mortgage interest rate.

E16. EXTRA INSUR.,MAINT. IN YEAR 1 (% OF ORIG.INV.)
All miscellaneous costs which cannot be entered elsewhere should be included along with insurance and maintenance costs here. Costs are in percent of original investment (total system cost).

E17. ANNUAL % INCREASE IN ABOVE EXPENSES ....
Annual percent increase in insurance, maintenance, and miscellaneous costs covered by parameter E16.

E18. EFFECTIVE FEDERAL-STATE INCOME TAX RATE ....
Since state income tax paid is deductible on federal returns, the effective federal-state income tax rate is

$$(F + S - (F * S)) * 100$$

where F and S are the federal and state tax rates, respectively (between 0 and 1; not percent). These tax rates are assumed constant throughout the period of analysis. For states which allow income tax deductions for federal income tax paid, the effective tax rate is

$$(F + S - 2(F * S))*100/(1 - (F * S))$$

E19. TRUE PROP. TAX RATE PER $ OF ORIGINAL INVEST ..
Since property taxes are paid on assessed value rather than actual cost, the true property tax rate is

(TAX RATE ON ASSESSED VALUE) * (ASSESSED VALUE/SYSTEM COST)

E20. ANNUAL % INCREASE IN PROPERTY TAX RATE ....

Annual percent increase in the true property tax rate (supplied as parameter E19).

E21. STATE CREDIT IN TIER ONE......................

A "two-tier" state tax credit system is assumed. One rate is applied to costs up to some maximum investment and a second rate is applied to additional costs up to a second maximum. The state tax credit received is parameter E21 times the minimum of the system cost and E22, plus E23 times the remaining system cost above E22 but not in excess of E24.

E22. STATE CREDIT TIER ONE BREAK....................

Maximum investment credited at the rate given by parameter E21.

E23. STATE CREDIT IN TIER TWO......................

Tax credit rate on investment in excess of the cost specified for parameter E22.

E24. STATE CREDIT TIER TWO BREAK...................$

Cost above which no additional state tax credit is received (see E21 above).

E25. USEFUL LIFE FOR DEPREC. PURPOSES ....

The length of time over which the commercial system is to be depreciated to zero value. If this is greater than the length of the analysis (parameter E7), then this value may effect the estimated resale value (see parameter E14 above).

E26. % OF ST. LINE DEP. RATE (DC. BAL. DEPRC.) .....

The federal government allows several rates for writing off investments when the declining balance method is used. These rates are expressed as percentages of the straight line depreciation rate, e.g. set E26 to 200 for "double declining balance" depreciation.

CHAPTER 5

RUNNING AN ANALYSIS OR SERIES OF ANALYSES

An FCHART analysis consists of a system thermal performance evaluation, a purchased energy summary and, optionally, a life-cycle economic analysis. The analysis results depend upon the system chosen, the options selected, and the values given to the applicable parameters and fuel costs. Describing a system and choosing to include or omit the life-cycle economics are covered in Chapter 1. Specifying values for the pertinent parameters is discussed in Chapter 2. Chapter 4 describes fuel cost input along with economics. Once a system has been chosen and parameters set, the commands described in this chapter may be used to produce a single FCHART analysis or a series of related analyses.

The RUN command causes an analysis or multiple analyses to be performed. If the command OPTIMIZE has been entered, RUN will give an analysis of the system with the selected parameter at its optimum value. The LOOP command specifies a series of values for any parameter. If LOOP is used, RUN will produced analyses with the "LOOPed" parameter at each of the specified values. Both LOOP and OPTIMIZE require that the user enter system cost data as a function of the parameter being varied. This is done using the OPDATA command, also described in this chapter.

5.1 The RUN Command

Use the RUN command to run an analysis and to specify the desired location and thermal analysis output format. The form of the RUN command is

```
RUN (location number)  (SHORT or LONG)
```

The specifications in parentheses are optional and may occur in either order. If a specification is ommitted, then the most recently used (or default if none specified) location number or output length is used. The defaults are Ottawa, Ontario. and LONG (monthly) thermal performance output. Location numbers for the cities in the data base supplied with the program appear in Appendix B.

5.1.1 Examples

To run an analysis in location 44 and receive the short thermal analysis output table, use

```
run short 44
```

or

```
run 44 short
```

To run another analysis in the same location with the same output format, just type

```
run
```

If you want to keep the same location but switch from SHORT to LONG **thermal analysis** output, use

```
run long
```

The length of the economic analysis output is determined by the economic parameter E1.

5.2 Analysis Output

The thermal analysis output table you get depends on which components you have included in your system. The following abbreviations are used to identify the monthly and yearly totals or averages in the output tables:

HT - total solar radiation incident upon aperture of collector
TA - average ambient temperature
SHLOAD - total space heating load
HWLOAD - total water heating load (including auxiliary tank losses)
LOAD - total load
QU - total useful energy gain of collector
QLOSS - total energy loss from storage
DELTE - total change in internal energy of storage
FNP - fraction of total load which is non-purchased energy
FDHW - fraction of domestic hot water load which is non-purchased energy
FW - fraction of the total load which is work input to the heat pump(s)

The purchased energy summary includes yearly total energy consumption and cost classified according to fuel type. The economic output is described in Chapter 6.

5.3 The LOOP Command

There are three forms of the LOOP command:

```
LOOP par. = a TO b STEP c
LOOP par. = a TO b MULT c
LOOP par. = a,b,c,d,e
```

The equals sign and the word TO is optional in each case. In the first form, the specified parameter is first set to the value a and an analysis performed. The parameter is then incremented by c and an additional analysis produced. This process is repeated as long as the parameter value does not exceed b. This form of the

LOOP command is similiar to a DO-loop in FORTRAN or a FOR-loop in BASIC.

In the second form, the parameter is first set to a, then multiplied by c until b is reached. In the first two forms of the command, b must be greater than or equal to a. When STEP is used, c must be greater than zero. When MULT is used, c must be greater than 1.

The third form of LOOP allows the user to list up to 5 values for the parameter named. One analysis is done for each value.

In each case, system cost and values for any dependent variables are set according to the optimization data supplied. It is required that the user enter optimization data for a parameter before that parameter appears on a LOOP command. Note that "system base costs" (parameters E8 and E9) must be set to system costs exclusive of any costs associated with parameters on LOOP or OPTIMIZE commands.

5.3.1 Examples

```
loop c1=10 to 50 step 10
```

Five analyses with collector areas of 10, 20, 30, 40 and 50.

```
loop c1=10 to 400 mult 2
```

Five analyses with collector areas of 25, 50, 100, 200 and 400.

```
loop s1=350,700,1500
```

Three analyses with tank capacity per unit collector area set to 350, 700 and 1500.

5.4 The OPTIMIZE Command

The format of the OPTIMIZE command is simply

```
OPTIMIZE par.
```

To optimize collector area, for example, type

```
OPTIMIZE C1
```

When OPTIMIZE is used, the value of the specified parameter which minimizes system life-cycle cost will be found. This optimum is assumed to be between the minimum and maximum values given in the optimization data. System cost and values for any dependent variables are set according to the optimization data as described in section 5.6. Note that "system base cost" (parameters E8 and E9) must be set to system costs exclusive of costs associated with any parameters named on LOOP or OPTIMIZE commands.

5.5 Interactions Between RUN, LOOP, and OPTIMIZE

Both LOOP and OPTIMIZE effect the next RUN command to be entered. LOOP can be used at any time to select a parameter to be varied the next time RUN is typed in. OPTIMIZE may be used before or after LOOP, or exclusive of LOOP, to select a parameter for optimization. When LOOP and OPTIMIZE are used together, the optimum value of the parameter on the OPTIMIZE command will be found for each value of the parameter on the LOOP command. There is no sensible reason for specifying the same parameter on both commands. After RUN is executed, the effects of any previously entered LOOP or OPTIMIZE commands are nil; each effects the next RUN and the next RUN only.

5.6 Loop and Optimization Data

In order to have meaningful economic results, the system cost must be changed when parameters associated with purchased components are varied. Since LOOP and OPTIMIZE vary parameters, the user must supply information to allow FCHART to compute the system cost accordingly. The command OPDATA is used to enter data points for cost as a function of parameter value. In addition, OPDATA may be used to specify how other "dependent" parameters are to be varied as functions of the "independent" parameters on LOOP or OPTIMIZE commands. It is required that the user enter optimization data before using LOOP or OPTIMIZE.

To enter optimization data, type OPDATA or OPDATA followed by the parameter you wish to enter data for. If you do not specify a parameter, FCHART asks you

```
INDEPENDENT VARIABLE ?
```

The term "independent variable" refers to the parameter you wish to specify on a LOOP or OPTIMIZE command. Answer this question by typing in the name of the parameter you choose. There is space in the program for data for five independent variables. If this space is full, the program will also ask which information you would like to write over (the question is "DELETE WHICH VARIABLE ?"). The deleted information will no longer be accessible. The next question,

```
DEPENDENT VARIABLES (UP TO 5) ?
```

gives you an opportunity to select up to five additional parameters to be varied as functions of your independent variable. For example, if you wish to optimize storage tank volume, varying the tank loss coefficient as a function of volume, you would answer S1 to the first question and S3 to the second. If you have no dependent variable in mind, the word NONE will signify this.

The relationship between the independent variable, any dependent variables, and system cost is described by entering "data points". Each data point consists of an independent variable value, dependent variable values, and the corresponding cost above the system base cost. For example, suppose collector FR-UL is the independent variable and collector FR-TAU-ALPHA is the dependent variable. If a collector with FR-UL of 4 and FR-TAU-ALPHA of 0.7 costs $1000, one of the data points you might use is

```
    4.0, 0.7, 1000
```

This means that if the independent variable has a value of 4, then the dependent variable will be 0.7 and the associated cost (collector cost, in this example) is $1000. Up to 5 data points may be used for each independent variable. When the independent variable value (as determined by the optimization algorithm or a LOOP command) is between two data points, the dependent variable values and cost are estimated using linear interpolation.

After you specify which independent and dependent variables you want, the program asks you for the number of data points you wish to use. If the relationships between the independent variable and each dependent variable are linear, then 2 data points will suffice. When quadratic, exponential, or other distinctly non-linear relationships are involved, more than 2 data points should be used to minimize the errors in computing the dependent variable values and costs.

```
    NUMBER OF DATA POINTS (2 TO 5) ?
```

You must use at least 2 and no more than 5. Then, you are asked to type in the number of data points you have specified, e.g.

```
    2
    ENTER 2 DATA POINTS
```

This may be done on as many or as few input lines as you wish. The independent variable values must be in increasing order. For optimization, the first independent variable value will be used as the minimum value and the last value as the maximum; the optimization algorithm will find the best value between the minimum and the maximum.

In general, part of the cost of a system will be eligible for state or federal tax credits and some will not. In addition, part of the cost will be related to the parameters named on LOOP or OPTIMIZE commands while the rest of the investment is independent of these parameters. For any analysis of any system, the total system cost is the sum of four parts: tax creditable cost related to parameters being varied, tax creditable costs independent of these parameters, non-tax creditable "fixed" system costs, and varying costs not eligible for tax credits. The two costs which are independent of any parameters named on LOOP or OPTIMIZE commands are to be supplied as economic parameters E8 and E9. Generally, these parameters must be reset whenever one decides to use LOOP or OPTIMIZE, or whenever LOOP or OPTIMIZE is no longer in effect. Costs which are related to varying parameters should be entered as optimization data.

For example, suppose collector area is to be optimized. Collector dependent costs are generally linear in collector area and might be approximately $250 per square meter. Collector area independent costs for a simple residential system might be $1000. If both of these costs are to be reported for tax credits, then parameter E8 should be set to 1000 and E9 to zero. The two data points below will allow FCHART to find the optimum collector area between 0 and 1000 square meters.

```
0,0       100,250000
```

The final OPDATA question

```
COST ELIGIBLE FOR TAX CREDITS (YES,NO)?
```

may be answered affirmatively to ensure that the proper tax credits are granted.

A few parameters, namely C10, T1, S1, S7 and S8, give quantities on a per unit collector area basis. Since the price of a storage tank, for example, is a function of tank capacity rather than capacity per unit collector area, cost data is a function of both collector area and these parameter values. For the parameters C10, T1, S1, S7 and S8, the values and costs used in data points should be in terms of the actual quantities independent of collector area. For example, suppose storage tank volume is the independent variable and tank loss coefficient is the dependent variable. If a tank with a capacitance of 420 KJ/Deg C has a loss coefficient of 2 W/Deg C-M2 and costs $100, one of the data points you might use would be

```
420, 2, 100
```

This expresses that a tank with a capacity of 420 KJ/Deg C (NOT KJ/Deg C-M2) and U-value of 2 W/Deg C-M2 costs $100.

5.7 LOOP and OPTIMIZATION Examples

(1) The design variable of greatest concern for many solar space or water heating systems is collector area. This example shows how to optimize collector area, assuming storage capacity to be a function of collector area. Since storage capacity is generally sized according to the collector area used, the storage capactiy parameters S1, S7 and S8 express capacity in terms of collector area. Thus only the collector area parameter C1 needs to be varied in order to optimize under the assumption of constant collector area to storage capacity ratio.

The first step is to enter optimization data. We assume that the collector area dependent cost of $250 per square meter and the system base cost of $1000 are both eligible for tax credits. To enter this cost data, type OPDATA.

```
quick space active fplate nloss nleak nhx liq hx ua fuel econ
   SYSTEM DESCRIPTION COMPLETE

?
opdata
```

You will then be asked

```
    INDEPENDENT VARIABLE ?
```

Answer C1 to get the next question

```
   c1
     DEPENDENT VARIABLES (UP TO 5) ?
```

Since the only parameter to be varied is C1, type in NONE. The next question is

```
   none
     NUMBER OF DATA POINTS (2 TO 5) ?
```

We assume cost to be linear in collector area, so two data points will suffice (answer 2). You are then asked to enter these points

```
     2
      ENTER 2 DATA POINTS
```

In response, enter

```
     0,0 1000,250000
```

This means that with zero collector area, the total system cost will be the base cost (parameter E8 plus E9). With 1000 square meters, the cost will be the base cost plus $250000. For collector areas between 0 and 1000, the cost will be calculated by linear interpolation. The optimization algorithm will only search between the minimum and maximum values supplied, i.e. 0 and 1000.

The last question is

```
   COST ELIGIBLE FOR TAX CREDITS (YES,NO)?
```

Answer YES. Now you can enter the OPTIMIZE command

```
   yes
   ?
   optimize c1
```

Since the system base cost is $1000, set

```
    e8=1000
```

and

```
     e9=0
```

Then type

```
     run
```

to get the optimum collector area and the corresponding analysis results. If you have used the default liquid-based space heating system presented in Chapter 2, these are the results you will receive

```
?
run

****************   FCHART  ANALYSIS   (VERSION 4.1)  ****************
 OTTAWA INT'L   ONT      LATITUDE 45.3

          ****  LOOP AND OPTIMIZATION PARAMETERS  ****
 C1. COLLECTOR AREA .................................    24.63 M2

                       THERMAL PERFORMANCE
              HT       TA    SHLOAD       QU     QLOSS     DELTE  FNF
             (GJ)  (DEG-C)  (GJ)         (GJ)   (GJ)      (GJ)
      JAN    8.37   -10.9   21.36        3.08    0.01      0.02 0.14
      FEB   10.15    -9.5   18.49        3.99    0.02     -0.01 0.22
      MAR   13.46    -3.1   15.54        5.76    0.03      0.02 0.37
      APR   12.85     5.6    8.81        5.73    0.06      0.02 0.64
      MAY   14.26    12.4    4.30        5.04    0.36      0.38 1.00
      JUN   14.23    18.2    1.05        2.34    0.90      0.39 1.00
      JUL   15.03    20.7    0.24        1.10    1.01     -0.14 1.00
      AUG   14.11    19.3    0.67        1.67    1.01      0.0  1.00
      SEP   11.73    14.6    2.92        2.92    0.57     -0.57 1.00
      OCT    9.43     8.7    6.89        4.44    0.05     -0.11 0.65
      NOV    5.28     1.4   11.86        2.03    0.01      0.01 0.17
      DEC    5.99    -7.7   18.91        2.10    0.00     -0.01 0.11
      YR   134.90     5.8  111.03       40.21    4.03      0.00 0.33

                    PURCHASED ENERGY SUMMARY

                        GAS      ELECTRIC     OIL      TOTAL
        USE (GJ)        0.0       74.84       0.0      74.84
        COST ($)        0.0      449.07       0.0     449.07

          LIFE CYCLE COST ANALYSIS OF CURRENT SYSTEM

       BASE COST OF SYSTEM             $     1000.
       COST ABOVE BASE COST            $     6158.
       TOTAL COST OF SYSTEM            $     7158.
       DOWN PAYMENT                    $      716.
       TOTAL TAX CREDITS               $     4581.
       ANNUAL MORTGAGE PAYMENT         $      656. FOR 20 YEARS

                         UNDISCOUNTED  ANNUALIZED  PRESENT WORTH
       ENERGY COST           25719        1014         9955
       TOTAL  COST           38695        1401        13757
?
```

To check how much the thermal performance and life-cycle cost vary for collector areas near the optimum, use the command

```
loop c1=15 to 45 step 10
```

followed by

```
run
```

Since this produces two or three pages of output, you may prefer to use RUN SHORT to get short thermal performance output and set E1 to 1 for the short economic printout. Note that system cost is calculated from the optimization data here just as it was on the optimizing run. If you wish to run again without varying C1, you must reset parameter E8 to include collector area dependent costs.

(2) LOOP and OPTIMIZE may be used together to approximate two-variable optimization. In this example, LOOP is used to vary storage tank capacitance per unit collector area while OPTIMIZE finds the optimum collector area for each tank capacitance ratio. By comparing the life-cycle costs of all systems, the optimum combination of collector area and storage volume can be determined. To separate the effects of storage capacitance and storage loss area, the storage tank U-value is varied as a function of capacity so that all tanks considered have the same UA product. This also demonstrates the use of dependent variables.

To begin with, the cost data and relationship between tank capacity and U-value required by OPDATA must be prepared.

COMPONENT	COST	TAX CREDITS ?
Collector	$200 per M2	YES
Tank		YES
Uninsulated	$ 50 per M2 surface area	
Insulation	$150 per M3 (Conductivity K = 0.1 watts/Deg C-M)	

Assuming the tank to be a cylinder with height to diameter ratio of 2, the relationship between surface area and capacitance is

```
   V = CAPACITANCE/(DENSITY * SP. HEAT)
   D = (2 * V/PI) ** (1/3)
AREA = 2.5 * PI * (D**2)
```

To get a constant tank UA, the thickness of the tank insulation must be varied with tank area so that U = UA/AREA. Since the U-value is the insulation conductivity divided by the thickness, the volume of insulation required is

```
VOL = AREA * K/U
    = K * (AREA**2)/UA
```

For tank capacities between 0 and 100,000 KJ/Deg C (approx. 24,000 liters or 6000 gallons), the costs assuming a UA of 10 watts/Deg C are summarized below.

CAPACITY	SURF. AREA	U-VALUE	INS. COST	TOTAL COST
0	0	-	0	0
1000	2.2	4.5	7	117
10000	10	1.0	150	650
50000	30	0.3	1500	3000
100000	48	0.2	3600	6000

The tank costs can be entered into the optimization data base as follows

```
forget

 WOULD YOU LIKE INSTRUCTIONS (YES,NO,QUICK) ?
quick space active fplate nloss nleak nhx liq hx ua fuel econ

   SYSTEM DESCRIPTION COMPLETE

 ?
opdata

 INDEPENDENT VARIABLE ?
s1

 DEPENDENT VARIABLES (UP TO 5) ?
s3

 NUMBER OF DATA POINTS (2 TO 5) ?
5

 ENTER 5 DATA POINTS
       0      1000        0
    1000       4.5      117
   10000       1.0      650
   50000       0.3     3000
  100000       0.2     6000

 COST ELIGIBLE FOR TAX CREDITS (YES,NO)?
yes
```

collector costs are entered as in example (1) above using the two data points

    0,0   200,40000

```
opdata

 INDEPENDENT VARIABLE ?
c1

 DEPENDENT VARIABLES (UP TO 5) ?
none

 NUMBER OF DATA POINTS (2 TO 5) ?
2

 ENTER 2 DATA POINTS
0,0 200,40000

 COST ELIGIBLE FOR TAX CREDITS (YES,NO)?
yes
```

The system base cost, entirely eligible for tax credits, is $2000 so set

E8 = 2000
E9 = 0

```
 ?
e8=2000
 ?
e9=0
```

Now select a series of storage capacity ratios

```
?
loop s1=200 to 400 step 50
```

and specify that collector area is to be optimized

```
?
opt c1
```

You may also want to set

```
?
e1=1
```

to get short economic output and use the SHORT option on the RUN command.
When you type

```
run short
```

You will get 5 analyses for storage capacity to collector area ratios of 200, 250, 300, 350, and 400. If you started with the default liquid-based space heating system presented in Chapter 2, the best of these systems economically has the minimum Present Worth of Total Cost of $13,902 as shown below.

```
****************   FCHART  ANALYSIS   (VERSION 4.1)  *****************

 OTTAWA INT'L   ONT     LATITUDE 45.3

          ****  LOOP AND OPTIMIZATION PARAMETERS  ****
 S1. TANK CAPACITY/COLLECTOR AREA ..................  300.00 KJ/DEG C-M2
 S3. HEAT LOSS COEFFICIENT .........................    1.01 W/M2-DEG C
 C1. COLLECTOR AREA ................................   33.29 M2

                     THERMAL PERFORMANCE

          HT      TA    SHLOAD       QU     QLOSS     DELTE   FNP
         (GJ)  (DEG-C)  (GJ)        (GJ)    (GJ)      (GJ)
  YR   182.32     5.8   111.03     53.37    9.69     -0.00 0.39

                  PURCHASED ENERGY SUMMARY

                      GAS     ELECTRIC     OIL       TOTAL
       USE (GJ)       0.0      67.35       0.0       67.35
       COST ($)       0.0     404.10       0.0      404.10

                     ECONOMIC ANALYSIS

       BASE COST OF SYSTEM             $     2000.
       COST ABOVE BASE COST            $     7307.
       TOTAL COST OF SYSTEM            $     9307.
       TOTAL TAX CREDITS               $     5957.
       PRESENT WORTH OF TOTAL COST     $    13902.
```

This system has a collector area of 33.29 square meters and a storage capacity per unit collector area of 300 KJ/Deg C-M2. This system provides 39% of the house heating requirement. To get a better idea of where the optimum actually is, you may want to try optimizing storage capacity for a series of collector areas near what appears to be the optimum.

CHAPTER 6

ECONOMICS

The analysis of a system which utilizes solar energy is not complete until the costs associated with the installation and operation of the system are known. Since these systems typically represent a large investment which must be recovered over a period of several years, the decision to invest this capital must be based on the expectation that the amount of future cost avoided is sufficently large when compared with the original investment. This comparison must be based on costs projected over the life of the system and expressed in terms of their value at the time the investment is made. In other words, the economic analysis of solar equipment must be based on life cycle costs and must consider the time value of money. Furthermore, in order to determine avoided costs, a similar analysis must be performed on the most feasible alternative to the solar investment and the results compared on a rational basis.

In accordance with the above requirments, FCHART 4.0 will perform a life cycle economic analysis of the current system and compare it with the analysis of a designated reference system. The analysis considers present and future costs associated with system ownership and operation and determines the total amount, in present dollars, of these expenditures. The costs which are considered are the following:

- Down payment
- Cost of capital(mortgage principal and interest)
- Insurance and maintainence
- Property taxes
- Auxiliary fuel cost
- State and federal alternative energy tax credits
- State and federal income tax deductions
- Depreciation(commercial installations only)
- System resale value

FCHART computes the dollar amount of each of these costs in each year based on user supplied parameter values and system thermal analysis results. The sum of these costs in one year is the net annual cash flow for the year and is discounted at the specified market discount rate to determine its present worth. The sum of the discounted net cash flows is the present worth of system life cycle costs and is the primary economic figure of merit calculated by the program.

The FCHART economics package may be used in two different modes. The first mode calculates life cycle costs for the system and economic parameter values specified or defaulted by the user prior to the RUN command. The second mode allows a user to compare the life cycle costs of two different systems and computes life cycle savings, rate of return and other comparative economic indicators.

Output detail in either of these modes may be controlled by the user, with detail ranging from a simple total cost summary to an itemized annual print out of all costs.

The economic processor computes fuel costs based on user entered utility rate data and program generated thermal analysis results. Utility rate data may be entered using the FLDATA command and reviewed using the LIST FLDATA command. Fuel data may be entered for three types of fuel and may be formatted as either a sequence of values representing future fuel costs or as a set of values representing a block rate structure of up to five blocks inflating at a fixed percentage per year.

The FCHART thermal analysis computes the auxiliary energy requirment of the system under analysis. This calculation may be bypassed so that the economic processor can be used by itself. To bypass this calculation procedure and run the economic processor for user-specified auxiliary requirments, type in:

```
forget(if necessary)      nospace
noactive  input
fuel econ
```

Then enter monthly auxiliary requirments as parameter L6 and set the economic parameters to their appropriate values. The economic analysis which will be performed after the next RUN command will use the values of parameter L6 as the auxiliary energy requirment in calculating the cost of energy used. This allows the FCHART economic package to be used to evaluate any system for which total auxiliary requirments are known.

The remainder of this chapter is divided into four parts. First, the basic life cycle cost analysis is presented and explained. Second, comparative analyses between different systems are presented. Third, the entry of fuel cost data into FCHART is documented. Last, a detailed example is presented in which the thermal and economic performance of a solar domestic hot water system is evaluated and the optimum collector area is determined.

6.1 Basic Life Cycle Cost Analysis

System life cycle costs are analyzed immediately after the thermal analysis whenever a RUN command is entered and the economics package is enabled. (For instructions on enabling the economics package see Chapter 2) The degree of output detail and type of analysis are specified by the values of parameters E1 and E2. Parameter E1 determines the level of output detail printed. Allowable values of E1 are 1,2 or 3, with 1 giving the minimum amount of detail and 3 giving maximum. The economic output in Figures 6.1.1, 6.1.2 and 6.1.3 was produced using the system description and parameter values of the Chapter 2 example run and values of E1 of 1, 2 and 3, respectively. This output represents a basic life cycle cost analysis of the current system (E2 set to 1). The use of the comparative economics feature to compute life cycle savings will be discussed in Section 6.2.

```
forget

 WOULD YOU LIKE INSTRUCTIONS (YES,NO,QUICK) ?
quick space active fplate nloss nleak nhx liq hx ua fuel econ
   SYSTEM DESCRIPTION COMPLETE

 ?
e2=1
 ?
e1=1
 ?
run short

****************    FCHART   ANALYSIS    (VERSION 4.1)   ****************
 OTTAWA INT'L    ONT      LATITUDE 45.3

                              THERMAL PERFORMANCE

                HT        TA    SHLOAD        QU       QLOSS     DELTE   FNP
               (GJ)   (DEG-C)  (GJ)         (GJ)      (GJ)      (GJ)
       YR    273.83      5.8   111.03       65.23      8.37     -0.00  0.51

                         ① PURCHASED ENERGY SUMMARY

                                  GAS      ELECTRIC     OIL        TOTAL
            USE (GJ)              0.0       54.18       0.0        54.18
          ② COST ($)              0.0      325.07       0.0       325.07

                             ECONOMIC ANALYSIS

          ③ INITIAL COST OF SYSTEM          $    6000.
          ④ TOTAL TAX CREDITS               $    3840.
          ⑤ PRESENT WORTH OF TOTAL COST     $   10393.
 ?
```

Figure 6.1.1

(circled numbers refer to text)

```
 e1=2
  ?
 run short

 ****************    FCHART   ANALYSIS    (VERSION 4.1)   ****************
  OTTAWA INT'L    ONT      LATITUDE 45.3

                               THERMAL PERFORMANCE

                 HT        TA    SHLOAD        QU       QLOSS     DELTE   FNP
                (GJ)   (DEG-C)  (GJ)         (GJ)      (GJ)      (GJ)
        YR    273.83      5.8   111.03       65.23      8.37     -0.00  0.51

                          PURCHASED ENERGY SUMMARY

                                  GAS      ELECTRIC     OIL        TOTAL
            USE (GJ)              0.0       54.18       0.0        54.18
            COST ($)              0.0      325.07       0.0       325.07

                LIFE CYCLE COST ANALYSIS OF CURRENT SYSTEM

           INITIAL COST OF SYSTEM           $    6000.
           DOWN PAYMENT                     $     600.
           TOTAL TAX CREDITS                $    3840.
         ⑥ ANNUAL MORTGAGE PAYMENT          $     550. FOR 20 YEARS
                             UNDISCOUNTED  ANNUALIZED  PRESENT WORTH
         ⑦ ENERGY COST           18618         734         7207
         ⑧ TOTAL  COST           29495        1059        10393
  ?
```

Figure 6.1.2

(circled numbers refer to text)

```
                           FCHART - A DESIGN PROGRAM
     FROM THE SOLAR ENERGY LABORATORY OF THE UNIVERSITY OF WISCONSIN
                         VERSION 4.1    5/1/82

 WOULD YOU LIKE INSTRUCTIONS (YES,NO,QUICK) ?
quick space active fplate nloss nleak nhx liq hx ua fuel econ

   SYSTEM DESCRIPTION COMPLETE

 ?
e2=1
 ?
e1=3
 ?
run short

****************   FCHART  ANALYSIS   (VERSION 4.1)  ****************

 OTTAWA INT'L   ONT     LATITUDE 45.3

                          THERMAL PERFORMANCE

             HT       TA    SHLOAD      QU     QLOSS    DELTE  FNP
            (GJ)   (DEG-C)  (GJ)       (GJ)    (GJ)     (GJ)
      YR   273.83     5.8  111.03     65.23     8.37    -0.00 0.51

                       PURCHASED ENERGY SUMMARY

                           GAS     ELECTRIC     OIL      TOTAL
          USE (GJ)         0.0       54.18      0.0       54.18
          COST ($)         0.0      325.07      0.0      325.07

                LIFE CYCLE COST ANALYSIS OF CURRENT SYSTEM

          INITIAL COST OF SYSTEM          $    6000.
          DOWN PAYMENT                    $     600.
          TOTAL TAX CREDITS               $    3840.
          ANNUAL MORTGAGE PAYMENT         $     550. FOR 20 YEARS

⑨       ⑩      ⑪      ⑫       ⑬      ⑭       ⑮       ⑯       ⑰       ⑱       ⑲       ⑳

   ****INFORMATION****   ******SYSTEM COSTS******* *ENERGY* ***INDICATORS****
     END    IN-   COMM                            TAX     NET     NET   PW OF   CUMU-
   OF YR TEREST DEPREC    LOAN  MAINT    PROP  CREDIT    FUEL    CASH    CASH  LATIVE
YR PRINC   PAID DEDUCT   PAYMT  & INS     TAX  RESALE    COST    FLOW    FLOW      PW
0    5400      0      0     600      0       0    3840       0   -3239   -3239   -3239
1    5282    432      0     550     60     120     193     325     862     798   -2441
2    5155    423      0     550     64     127     192     358     906     777   -1664
3    5017    412      0     550     67     135     192     393     954     757    -907
4    4868    401      0     550     71     143     190     433    1007     740    -167
5    4708    389      0     550     76     151     189     476    1064     724     556
6    4534    377      0     550     80     161     188     524    1126     710    1266
7    4347    363      0     550     85     170     187     576    1195     697    1963
8    4145    348      0     550     90     180     185     633    1269     686    2649
9    3926    332      0     550     96     191     183     697    1351     676    3324
10   3691    314      0     550    101     203     181     767    1440     667    3991
11   3436    295      0     550    107     215     179     843    1537     659    4650
12   3161    275      0     550    114     228     176     927    1643     653    5303
13   2863    253      0     550    121     241     173    1020    1759     647    5950
14   2543    229      0     550    128     256     170    1122    1886     642    6592
15   2196    203      0     550    136     271     166    1234    2025     638    7231
16   1822    176      0     550    144     288     162    1358    2177     635    7866
17   1417    146      0     550    152     305     158    1494    2343     633    8499
18    981    113      0     550    162     323     153    1643    2525     632    9131
19    509     78      0     550    171     343     147    1807    2724     631    9762
20      0     41      0     550    182     363     141    1988    2941     631   10393
TOTAL        5600      0   11600   2207    4414    7345   18618   29495   10393
PW OF TOT    3215      0    6000    935    1871    5620    7207   10393

                        UNDISCOUNTED  ANNUALIZED   PRESENT WORTH
         ENERGY COST        18618         734          7207
         TOTAL  COST        29495        1059         10393
```

Figure 6.1.3

(circled numbers refer to text)

Referring to Figure 6.1.1, the output quantites are defined as follows:

1. The purchased energy summary lists the usage of energy in each category estimated by the thermal analysis section of FCHART, as well as the total energy use for all fuel types. The effects of device efficiency have been included in this figure.

2. This line represents the cost of energy consumed in each fuel category as well as the total cost of purchased energy. These costs represent first year costs and are computed using the data entered with the FLDATA command.

3. The initial cost of the system is found by adding parameters E8 and E9. Parameter E9 has been included to allow life cycle cost analysis of systems which include equipment not elgible for alternative energy tax credits, such as parallel heat pumps in some localities.

4. This is the amount of tax credit for which the system is elgible. FCHART assumes that the owner's income is sufficiently high that all tax credits may be taken within one year of purchase.

5. This is the present worth of the annual net cash flows and is calculated by discounting each cash flow back to year zero at the market discount rate, parameter E15.

Economic output produced when E1=2(Figure 6.1.2) contains the same information as that produced when E1=1, with the addition of:

6. Mortgage payment. This is the annual payment required to pay back the total system cost less down payment.

7. Energy cost for the system, expressed as an undiscounted total over the life of the system(simple summation), the present worth of energy costs(summation of discounted costs, with discounting at the market rate, parameter E15), and the annualized amount going to purchased energy(the amount of a regular annuity over the life of the system with a present worth equal to the present worth in column 3).

8. Total cost(energy plus ownership) for the system expressed in the same terms as item 7, above.

When parameter E1 is set to 3, quantites 1 through 8 are printed, with the addition of an annual summary of costs, see Figure 6.1.3. The annual summary is broken down into four categories. The first, 'Information', consists of:

9. The year in which costs are incurred.

10. Loan principle remaining at the end of the year.

11. The amount of the loan payment which went to interest on the principle.

12. The amount of depreciation deductions allowed in the year(income and commercial buildings only).

The second category, 'System Costs', consists of:

13. Down payment(year 0) and loan payment (years 1 thru 20).

14. Maintainence, insurance and miscellaneous costs.

15. Property tax on the system.

16. Alternative energy tax credits received(year 0); reduction in income tax in years 1 thru 20 due to interest, property tax and depreicitaion deductions, if applicable; and cost(savings) resulting from resale of the system at the end of the analysis period(included in year 20).

The third category, 'Energy', consists of:

17. Net cost of purchased energy. For residential buildings, this is the total cost of auxiliary energy. For income or commercial systems, the effect on income taxes of deducting fuel costs from income has been included in this figure. That is, this cost is (1-TAXRATE) times total purchased energy cost in one year.

The last category, 'Indicators', consists of:

18. Net cash flow. This is the total cost of the system in each year. A savings is represented here as a negative cost, as in year 0 of

this example, since tax credits are assumed to be recieved immediately after the system is purchased and are much larger than the only other cost at this time, the down payment. This column may be expressed as the sum of the five columns preceeding it, namely:

$$18 = 13 + 14 + 15 - 16 + 17.$$

19. This is the value of the year's net cash flow discounted to year 0 at the market discount rate.

20. This is a running sum of the present worth of system costs.

6.2 Comparison of Life Cycle Costs for Different Systems

The FCHART economics package includes a feature which allows the user to compare the life cycle costs of different systems. There are two stages in the comparison process. First, the reference system must be defined by setting the appropriate system description variables, parameter values and fuel costs. By setting parameter E2 to 1, the user indicates to FCHART that the system under analysis is a reference system. The RUN command is then entered and the thermal and economic analyses are performed. Next, the comparison system must be defined by re-setting the system variables, parameter values and fuel costs as required. With parameter E2 set to 2, the economic analysis package will compare the life cycle costs of the current system with those of the most recently run reference system. Varying levels of output detail are available. With E1 set to 1, economic analysis output contains one line in addition to that printed when E2=1(reference system run). This line is the present worth of total savings and is defined as the difference between the present worth of life cycle costs for the reference system and the present worth of life cycle costs for the current system.

With E1 set to 2, the output appears as in Figure 6.2.1. The lines headed 'Comparative Life Cycle Economics' represent the difference in energy costs and total costs for the two systems. These are expressed in undiscounted, present worth and annualized terms.

eg.

```
                         FCHART - A DESIGN PROGRAM
    FROM THE SOLAR ENERGY LABORATORY OF THE UNIVERSITY OF WISCONSIN
                          VERSION 4.1    5/1/82

 WOULD YOU LIKE INSTRUCTIONS (YES,NO,QUICK) ?
quick space active fplate nloss nleak nhx liq hx ua fuel econ

   SYSTEM DESCRIPTION COMPLETE

 ?
run short
```

This first run defines the reference system. Figure 6.2.1 shows the changes and the comparison of the modified system.

```
list c1
 C1. COLLECTOR AREA ..................................   50.00 M2
 ?
c1=65
 ?
list e8
 E8. TAX CREDITABLE SYSTEM BASE COST ...............$ 6000.00
 ?
e8=7000
 ?
list e11
 E11. TERM OF MORTGAGE ...............................   20.00 YEARS
 ?
e11=15
 ?
list e12
 E12. DOWN PAYMENT (% OF ORIGINAL INVESTMENT) .......   10.00 %
 ?
e12=5
 ?
list e2

 E2. REFERENCE OR COMPARISON SYSTEM (1 OR 2) ........    1.00
 ?
e2=2
 ?
list e1
 E1. ECONOMIC OUTPUT DETAIL (1,2 OR 3) ..............    2.00
 ?
e1=2
 ?
run short

***************   FCHART  ANALYSIS   (VERSION 4.1)  ****************
 OTTAWA INT'L   ONT     LATITUDE 45.3

                       THERMAL PERFORMANCE

              HT      TA   SHLOAD     QU      QLOSS     DELTE  FNP
             (GJ)  (DEG-C)  (GJ)     (GJ)     (GJ)      (GJ)
      YR   355.98     5.8  111.03    75.82    11.03    -0.00 0.58

                    PURCHASED ENERGY SUMMARY

                    GAS     ELECTRIC    OIL      TOTAL
        USE (GJ)    0.0      46.27      0.0      46.27
        COST ($)    0.0     277.59      0.0     277.59

              LIFE CYCLE COST ANALYSIS OF CURRENT SYSTEM

        INITIAL COST OF SYSTEM          $    7000.
        DOWN PAYMENT                    $     350.
        TOTAL TAX CREDITS               $    4480.
        ANNUAL MORTGAGE PAYMENT         $     777. FOR 15 YEARS

                        UNDISCOUNTED  ANNUALIZED  PRESENT WORTH
        ENERGY COST         15899         627         6154
        TOTAL  COST         27593        1023        10048

                  COMPARATIVE LIFE CYCLE ECONOMICS

                        UNDISCOUNTED  ANNUALIZED  PRESENT WORTH
        ENERGY SAVING        2719         107         1053
        TOTAL  SAVING        1917          35          346

        CUMULATIVE UNDISC. ENERGY SAVINGS EQUAL INCREASED
        INVESTMENT IN  12 YEARS

        CUMULATIVE UNDISC. NET SAVINGS EQUAL ZERO
        (BREAK EVEN POINT) IN  18 YEARS
 ?
```

FIGURE 6.2.1

```
e1=3
 ?
run short
                LIFE CYCLE COST ANALYSIS OF CURRENT SYSTEM

          INITIAL COST OF SYSTEM            $    7000.
          DOWN PAYMENT                      $     350.
          TOTAL TAX CREDITS                 $    4480.
          ANNUAL MORTGAGE PAYMENT           $     777. FOR 15 YEARS

     ****INFORMATION****  *****SYSTEM COSTS******* *ENERGY* ***INDICATORS****
       END     IN-   COMM                             TAX     NET     NET  PW OF  CUMU-
     OF YR TEREST DEPREC     LOAN MAINT     PROP CREDIT    FUEL    CASH   CASH LATIVE
YR   PRINC   PAID DEDUCT    PAYMT & INS      TAX RESALE    COST    FLOW   FLOW     PW
 0    6650      0      0      350     0        0   4480       0   -4129  -4129  -4129
 1    6405    532      0      777    70      140    235     278    1029    953  -3176
 2    6141    512      0      777    74      148    231     305    1074    920  -2256
 3    5855    491      0      777    79      157    227     336    1122    890  -1365
 4    5546    468      0      777    83      167    222     369    1174    863   -502
 5    5213    444      0      777    88      177    217     406    1231    838    335
 6    4853    417      0      777    94      187    212     447    1293    815   1150
 7    4465    388      0      777    99      199    205     492    1361    794   1944
 8    4045    357      0      777   105      211    199     541    1435    775   2720
 9    3592    324      0      777   112      223    191     595    1515    758   3478
10    3102    287      0      777   118      237    183     655    1603    742   4220
11    2573    248      0      777   125      251    175     720    1698    728   4949
12    2002    206      0      777   133      266    165     792    1802    716   5664
13    1385    160      0      777   141      282    155     871    1916    705   6369
14     719    111      0      777   149      299    143     958    2040    694   7063
15       0     58      0      777   158      317    131    1054    2175    686   7749
16       0      0      0        0   168      336    117    1160    1545    451   8200
17       0      0      0        0   178      356    124    1276    1684    455   8655
18       0      0      0        0   188      377    132    1403    1837    460   9115
19       0      0      0        0   200      400    140    1543    2003    464   9579
20       0      0      0        0   212      424    148    1698    2185    469  10048
TOTAL        5003      0    12005  2574     5154   8032   15899   27593  10048
PW OF TOT    3248      0     7001  1091     2185   6380    6154   10048

                           UNDISCOUNTED  ANNUALIZED  PRESENT WORTH
          ENERGY COST          15899         627         6154
          TOTAL  COST          27593        1023        10048

                   COMPARATIVE LIFE CYCLE ECONOMICS

     **REFERENCE SYSTEM*** ***CURRENT SYSTEM**** *******SAVINGS*******
        SYSTEM    ENERGY         SYSTEM    ENERGY        NET  PW OF     CUM.
YR       COST      COST           COST      COST        SAVE   SAVE       PW
 0      -3239         0          -4129         0         890    890      890
 1        537       325            752       278        -166   -154      735
 2        548       358            768       305        -167   -143      591
 3        561       393            786       336        -167   -132      458
 4        574       433            805       369        -167   -122      335
 5        588       476            825       406        -166   -113      221
 6        603       524            846       447        -166   -104      116
 7        619       576            869       492        -165    -96       19
 8        636       633            894       541        -165    -89      -70
 9        654       697            920       595        -164    -81     -152
10        673       767            948       655        -162    -75     -228
11        694       843            978       720        -160    -68     -297
12        716       927           1010       792        -158    -62     -360
13        739      1020           1045       871        -156    -57     -418
14        764      1122           1082       958        -152    -51     -470
15        791      1234           1121      1054        -148    -46     -517
16        819      1358            386      1160         632    184     -333
17        850      1494            409      1276         659    178     -155
18        882      1643            434      1403         688    172       16
19        916      1807            460      1543         721    167      183
20        953      1988            487      1698         756    162      346
TOTAL   10878     18618          11696     15899        1917    346
PW TOT   3189      7207           3895      6154         346

                           UNDISCOUNTED  ANNUALIZED  PRESENT WORTH
          ENERGY SAVING        2719         107         1053
          TOTAL  SAVING        1917          35          346

          CUMULATIVE UNDISC. ENERGY SAVINGS EQUAL INCREASED
          INVESTMENT IN  12 YEARS

          CUMULATIVE UNDISC. NET SAVINGS EQUAL ZERO
          (BREAK EVEN POINT) IN  18 YEARS
```

FIGURE 6.2.2

When E1 is set to 3, in addition to the year by year life cycle cost analysis of the current system, a year by year cost comparison is printed, with costs broken down into system and energy categories for both the reference system and the current system. See Figure 6.2.2. The column labeled 'NET SAVE' in this output is the difference between the sum of the first two columns(net cost for the reference system) and the sum of the second two columns(net cost for the current system). Net savings are also expressed in present dollars in the next to last column and as a running sum of present dollars in the last column.

6.3 Entering Fuel Cost Data

The commands FLDATA and LIST FLDATA are used to enter and list fuel cost data. Fuel cost data may be entered in two different formats for three different fuel types. The first format is a block rate structure of up to five blocks, all of which are inflated at a fixed rate per year. Each block consists of a cost per unit of energy in that block along with the maximum amount of energy usage associated with the block. When this format is used, all cost data must be entered on one line, e.g., if rates are in three blocks, three pairs of numbers must be entered, followed by a carriage return. The second format is a sequence of up to 40 values representing cost in dollars per unit of energy(MMBTU or GJ) for each year of the analysis.

The three fuel categories are labeled gas, electric and oil. These are keyed to system auxiliary devices through the parameters A1(for space heating auxiliary) and A3(for water heating auxiliary). All heat pumps are assumed to run on electricty so heat pump auxiliary costs are calculated using electric category data. It is possible to specify a system which uses all three fuel types, for example, a combined space and DHW system with (series) heat pump delivery device, oil auxiliary space heat(A1=3) and gas hot water auxiliary(A3=1). In this case, fuel cost for heat pump operation will be calculated using the cost data entered in the electric category, fuel cost for space heating auxiliary will be calculated using data entered in the oil category and hot water auxiliary cost will be calculated using the gas category data.

Fuel cost data are entered in units of dollars per unit of energy, i.e., $/MMBTU or $/GJ. The energy units used should be consistent with the units mode of the program, MMBTU for English units, GJ for SI units. If the unit system mode of the program is changed by entering the UNITS command, fuel cost data will be converted along with other parameter information.

Once entered, fuel cost data may be displayed by typing in the command:

```
list fldata
```

FUEL COST DATA ENTRY EXAMPLE

Fuel cost data are to be entered for two fuel types, gas and electricty. Gas is priced at $4.24 per (GJ) for the first 15 (GJ) purchased in a month, with each additional (GJ) priced at $4.64. These prices include the current Purchased Gas Adjustment (PGA) factor. Entry of these rates into FCHART proceedas as follows:

```
fldata     ;Call up fuel data entry routine.
 GAS, ELECTRIC OR OIL ?
gas        ;Gas rates to be entered.
  BLOCK RATES OR SEQUENCE OF AVERAGE COSTS (BLOCK,SEQ) ?
block      ;Block rate structure to be used.
  ANNUAL INFLATION RATE (PER CENT) ?
12         ;12 per cent annual fuel cost inflation.
 ENTER COST ($/GJ)    AND MAX USE (GJ)    FOR UP TO 5 BLOCKS
4.24 15 4.64 9999    ;All data must be entered on one line.
           ;FCHART responds with a prompt to indicate
           ; data entry is complete.
```

Electricty is priced at a flat 4.77 cents per kW-hr, including fuel adjustment. This works out to $13.98 per (GJ). Entry of this data is as follows:

```
fldata     ;Call up fuel data entry routine for electric rate entry.
 GAS, ELECTRIC OR OIL ?
electric   ;Electric rates to be entered.
 BLOCK RATES OR SEQUENCE OF AVERAGE COSTS (BLOCK,SEQ) ?
block      ;Block rate structure.
  ANNUAL INFLATION RATE (PER CENT) ?
 12        ;12 per cent annual inflation.
  ENTER COST ($/GJ)    AND MAX USE (GJ)    FOR UP TO 5 BLOCKS
 13.98 9999;Only one block for electricty.
  ?
           ;FCHART responds with a prompt after data entry
           ; is complete.
 list fldata   ;Request listing of data just entered.

           FUEL COST

 GAS  (BLOCK RATE STRUCTURE)
      ANNUAL INFLATION RATE  12.0 %
      BLOCK                  1      2
      COST ($/GJ)          4.2    4.6
      MAX. USE (GJ)       15.0 9999.0

 ELEC (BLOCK RATE STRUCTURE)
      ANNUAL INFLATION RATE  12.0 %
      BLOCK                  1
      COST ($/GJ)         14.0
      MAX. USE (GJ)     9999.0

 TYPE FLDATA TO ENTER OR CHANGE FUEL COSTS
  ?
```

6.4 Example

The following example is an analysis of a domestic hot water system to be installed on a residence in Ottawa, Ontario. This example will illustrate the development of FCHART parameter values for a particular system, the entry of fuel cost data, and the use of the comparative economics and optimization features.

A homeowner is interested in installing a solar domestic hot water system on her house. The existing system consists of a 52 gallon electric water heater and supplies 80 gallons of water per day at 140 degrees F. Mains water is supplied to the tank at a temperature of 50 degrees F year around. Tank standby losses are estimated to be 10,500 BTU/day in a 70 degree F environment. Since the existing water heater is only one year old and in good condition, the solar contractor has proposed to install a solar water heating system consisting of 62 square feet of single glazed selective surface liquid heating collectors and an 80 gallon tank which will preheat mains water before it is drawn into the existing tank. The system's fixed flow pump will circulate potable water through the collectors at a rate of 75 gallons per hour. Freeze protection is accomplished by draining the collectors when the pump is off. Site considerations dictate that approximately 25 feet of the collector piping be exposed to ambient conditions. This piping is 1 inch o.d. copper tubing and will be insulated with a 1 inch jacket of polyurethane with a PVC cover(k=0.012 BTU/ft-F-hr).

The installed cost of the system is $3100 and is to be paid off on a five year loan at an intrest rate of 12%. The system is elgibile for state and federal alternative energy tax credits and has a useful life of 20 years. Other relevant system parameters are:

Collector:
    FrUl=0.90 BTU/ft2-F-hr;
    Fr(ta)n=0.73;
    Incident angle modifier constant = 0.142;
    Slope = 40 degrees;
    Gross area = 62 square feet;
    Capacitance rate per unit area = 10 BTU/ft2-F-hr.

Transfer device:
    Inlet pipe (UA) = 1.7 BTU/hr-F;
    Outlet pipe (UA) = 1.7 BTU/hr-F.

Storage tank(preheat):
    Capacitance per unit collector area = 10.77 BTU/ft2-F;
    Height to diameter ratio = 1.9;
    Insulation loss coefficient = 0.88 BTU/ft2-hr-F.

Auxiliary tank(existing water heater):
    Overall (UA) = 6.25 BTU/hr-F;

Environmental temperature = 70 F;
Auxiliary heat = electric.

Economics:
System cost = $3100;
Loan down payment = 0%
Term of loan(mortgage) = 5 years;
Intrest rate = 12%;
All other values defaulted.

Fuel:
Electricty cost: $0.0477/kW-hr($13.98/MMBTU);
Fuel price inflation = 10% per year

Since this is a retrofit installation and the existing water heater could serve as-is for many more years, a comparison must be made between the life cycle cost of the solar system and the life cycle cost of electricty for the current water heater This is done by running FCHART twice, once for the existing water heater, designated the reference system, and again for the solar system. The existing water heater may be described to FCHART by the following dialogue (comments are preceeded by a semicolon and are in lower case type):

```
                        FCHART - A DESIGN PROGRAM
      FROM THE SOLAR ENERGY LABORATORY OF THE UNIVERSITY OF WISCONSIN
                         VERSION 4.1   5/1/82

 WOULD YOU LIKE INSTRUCTIONS (YES,NO,QUICK) ?
quick
     TYPE IN SYSTEM DESCRIPTION KEYWORDS, E.G. SPACE, ACTIVE, FPLATE ...
dhw           ;Hot water only system.
  FPLATE, CPC, OR IMAGE ?
fplate        ;We will need flat plates later.
  LOSS OR NLOSS ?
nloss         ;No pipes outside.
  LEAK OR NLEAK ?
nleak         ;No ducts.
  HX OR NHX ?
nhx           ;No heat exchanger.
  ECONOMICS OR NOECON ?
econ          ;Call for economic analysis.

  SYSTEM DESCRIPTION COMPLETE

units         ;Select English units
 ENGLISH UNITS
 ?
c1 = 0        ;No collectors on existing system.
 ?
s3 = 0        ;No preheat tank.
 ?
s5 = 6.25     ;(UA) of existing water heater.
 ?
s6 = 70       ;Tank is in heated part of house.
```

```
  ?
 13 = 80         ;80 GPD hot water needed.
  ?
 14 = 140        ;140 F set temperature.
  ?
 15 = 50         ;50 F mains temperature.
  ?
 e1 = 3          ;Call for annual economic output.
  ?
 e2 = 1          ;This is the reference system.
  ?
 e8= 0           ;No capital investment is required in
                 ; existing system.
  ?
 fldata          ;Call up fuel data entry routine.
   GAS, ELECTRIC OR OIL ?
  electric       ;Electric rates are to be entered.

   BLOCK RATES OR SEQUENCE OF AVERAGE COSTS (BLOCK,SEQ) ?
  block          ;Block rate structure is used.

   ANNUAL INFLATION RATE (PER CENT) ?
  10             ;10% per year fuel cost inflation.

   ENTER COST ($/MMBTU) AND MAX USE (MMBTU) FOR UP TO 5 BLOCKS
  13.98 10000  ;$13.98/MMBTU for up to 10,000 MMBTU.
   ?
  list fldata  ;List out fuel costs.

        FUEL COST

ELEC (BLOCK RATE STRUCTURE)
     ANNUAL INFLATION RATE  10.0 %
     BLOCK                  1
     COST ($/MMBTU)      14.0
     MAX. USE (MMBTU)10000.0

TYPE FLDATA TO ENTER OR CHANGE FUEL COSTS
 ?
list all

COLLECTOR PARAMETERS
 C1. COLLECTOR AREA ...................................    0.0  FT2
 C2. FR-UL PRODUCT ....................................    0.74 BTU/HR-FT2-DEG F
 C3. FR-TAU-ALPHA (NORMAL INCIDENCE) ..................    0.70
 C6. NUMBER OF COVERS (IF 0, C15 IS USED)..............    2.00
 C7. INDEX OF REFRACTION ..............................    1.53
 C8. EXTINCTION COEFFICIENT X LENGTH (KL)..............    0.04
 C9. INC. ANGLE MOD. CONSTANT (IF 0, C6-C8 USED).....    0.0
 C10. COLLECTOR FLOW RATE * SPECIFIC HEAT/AREA ......    9.69 BTU/HR-FT2-DEG F
 C12. COLLECTOR SLOPE ................................   43.00 DEGREES
 C13. COLLECTOR AZIMUTH ..............................    0.0  DEGREES
 C14. GROUND REFLECTANCE .............................    0.20
 C15. INCIDENCE ANGLE MODIFIERS (10,20,30,'40,50,60,70,80 DEG.)
     1.00  0.99  0.98  0.95  0.90  0.80  0.63  0.37
 STORAGE UNIT PARAMETERS
  S1. TANK CAPACITY/COLLECTOR AREA ....................   17.12 BTU/DEG F-FT2
  S2. STORAGE UNIT HEIGHT/DIAMETER RATIO .............    2.00
  S3. HEAT LOSS COEFFICIENT ..........................    0.0  BTU/HR-FT2-DEG F
  S4. ENVIRONMENT TEMPERATURE (-1000 FOR TENV=TAMB) ..   68.00 DEG F
  S5. HOT WATER AUXILIARY TANK UA ....................    6.25 BTU/HR-DEG F
  S6. HOT WATER AUX TANK ENVIRONMENT TEMPERATURE .....   70.00 DEG F

 LOAD PARAMETERS
  L3. HOT WATER USE ..................................   80.00 GALLONS/DAY
  L4. HOT WATER SET TEMPERATURE ......................  140.00 DEG F
  L5. WATER MAINS TEMPERATURE ........................   50.00 DEG F

 AUXILIARY PARAMETERS
  A3. HOT WATER AUXILIARY FUEL (1=GAS,2=ELEC,3=OIL) ..    2.
  A4. AUXILIARY WATER HEATER EFFICIENCY ..............    1.00

 ECONOMIC PARAMETERS
  E1. ECONOMIC OUTPUT DETAIL (1,2 OR 3) ..............    3.00
  E2. REFERENCE OR COMPARISON SYSTEM (1 OR 2) ........    1.00
  E3. CALCULATE RATE OF RETURN (YES=1,NO=2) ..........    2.00
  E4. INCOME PRODUCING BUILDING (YES=1,2=NO) .........    2.00
  E5. DEPRC: STR,LN.=1,DC.BAL.=2,SM-YR-DGT=3,NONE=4 ..    1.00
  E6. CONSIDER FEDERAL TAX CREDITS (YES=1,2=NO) ......    1.00
  E7. LENGTH OF ANALYSIS .............................   20.00 YEARS
  E8. TAX CREDITABLE SYSTEM BASE COST ...............$    0.0
  E9. NON-TAX CREDITABLE SYSTEM BASE COST ...........$    0.0
  E10. ANNUAL INCREASE IN PURCHASED ENERGY DEMAND ....    0.0  %/YR
  E11. TERM OF MORTGAGE ..............................   20.00 YEARS
  E12. DOWN PAYMENT (% OF ORIGINAL INVESTMENT) .......   10.00 %
  E13. MORTGAGE ANNUAL INTEREST RATE .................    8.00 %
  E14. RESALE VALUE (% OF ORIGINAL INVESTMENT) .......    0.0  %
  E15. ANNUAL NOMINAL (MARKET) DISCOUNT RATE .........    8.00 %
  E16. EXTRA INSUR.,LISET. IN YEAR 1 (% OF ORIG.INV.)     1.00 %
  E17. ANNUAL % INCREASE IN ABOVE EXPENSES ...........    6.00 %
  E18. EFFECTIVE FEDERAL-STATE INCOME TAX RATE .......   35.00 %
  E19. TRUE PROP. TAX RATE PER $ OF ORIGINAL INVEST ..    2.00 %
  E20. ANNUAL % INCREASE IN PROPERTY TAX RATE ........    6.00 %/YR
  E21. STATE CREDIT IN TIER ONE.......................   24.00 %
  E22. STATE CREDIT TIER ONE BREAK...................$10000.00
  E23. STATE CREDIT IN TIER TWO.......................    0.0  %
  E24. STATE CREDIT TIER TWO BREAK...................$10000.00
  E25. USEFUL LIFE FOR DEPREC. PURPOSES ..............   20.00 YEARS
  E26. % OF ST. LINE DEP. RATE (DC. BAL. DEPRC.) .....  150.00 %

  TYPE LIST FLDATA FOR FUEL COSTS
  ?
title existing hot water heater(electric)   ;Add title information.
  ?
run short        ;This gives short thermal analysis output
                 ;but does not affect the economic analysis.
```

```
****************   FCHART  ANALYSIS   (VERSION 4.1)  *****************
  EXISTING HOT WATER HEATER(ELECTRIC)

 OTTAWA INT'L   ONT     LATITUDE 45.3


                         THERMAL PERFORMANCE

                  HT       TA   HWLOAD      QU    QLOSS FDHW
                (MMBTU)(DEG-F)(MMBTU)  (MMBTU)(MMBTU)
        YR       0.0     42.5   25.75    0.00   -0.00 0.0


                      PURCHASED ENERGY SUMMARY

                         GAS     ELECTRIC    OIL      TOTAL
        USE (MMBTU)      0.0      25.75      0.0      25.75
        COST ($)         0.0     360.04      0.0     360.04


                LIFE CYCLE COST ANALYSIS OF CURRENT SYSTEM

        INITIAL COST OF SYSTEM          $       0.
        DOWN PAYMENT                    $       0.
        TOTAL TAX CREDITS               $       0.
        ANNUAL MORTGAGE PAYMENT         $       0. FOR 20 YEARS

    ****INFORMATION****  ******SYSTEM COSTS******* *ENERGY* ***INDICATORS****
     END     IN-  COMM                         TAX     NET     NET  PW OF CUMU-
   OF YR TEREST DEPREC   LOAN MAINT     PROP CREDIT    FUEL    CASH   CASH LATIVE
YR  PRINC   PAID DEDUCT  PAYMT & INS      TAX RESALE    COST    FLOW   FLOW     PW
 0      0      0      0      0     0        0      0       0       0      0      0
 1      0      0      0      0     0        0      0     360     360    333    333
 2      0      0      0      0     0        0      0     396     396    340    673
 3      0      0      0      0     0        0      0     436     436    346   1019
 4      0      0      0      0     0        0      0     479     479    352   1371
 5      0      0      0      0     0        0      0     527     527    359   1730
 6      0      0      0      0     0        0      0     580     580    365   2095
 7      0      0      0      0     0        0      0     638     638    372   2467
 8      0      0      0      0     0        0      0     702     702    379   2846
 9      0      0      0      0     0        0      0     772     772    386   3232
10      0      0      0      0     0        0      0     849     849    393   3626
11      0      0      0      0     0        0      0     934     934    401   4026
12      0      0      0      0     0        0      0    1027    1027    408   4434
13      0      0      0      0     0        0      0    1130    1130    415   4850
14      0      0      0      0     0        0      0    1243    1243    423   5273
15      0      0      0      0     0        0      0    1367    1367    431   5704
16      0      0      0      0     0        0      0    1504    1504    439   6143
17      0      0      0      0     0        0      0    1654    1654    447   6590
18      0      0      0      0     0        0      0    1820    1820    455   7045
19      0      0      0      0     0        0      0    2002    2002    464   7509
20      0      0      0      0     0        0      0    2202    2202    472   7982
TOTAL          0      0      0      0       0      0   20622   20622   7982
PW OF TOT      0      0      0      0       0      0    7982    7982

                             UNDISCOUNTED  ANNUALIZED  PRESENT WORTH
        ENERGY COST              20622         813         7982
        TOTAL  COST              20622         813         7982
```

We can do some 'back of the envelope' calculations to check our results and make sure FCHART is analyzing the system we think it is. The hot water heating load is mCp(Tset-Tmains)N, where m is the daily volume draw, Cp is the specific heat of water, (Tset-Tmains) is the required temperature rise, and N is the number of days in the year. Then:

Qhw= 80•(8.35)•1•(140-50)•365
21.94 MMBTU/year

This load, plus the tank's standby losses, is listed on the thermal analysis output under the heading 'HWLOAD'. Since there is no solar input to this system, this load must be supplied entirely by electricty. Then the annual electric consumption for the system will be:

Qelect = Qhw + Qloss
= 21.94 + (10,500)•365
= 25.77 MMBTU/year

This agrees with the electric consumption listed in the 'Purchased Energy Summary' and costs $360 per year, as shown on the output.

We are now ready to analyze the solar system using FCHART. The dialogue looks like this:

```
 ?
change transfer  ;Include pipe losses by changing the transfer components.
   LOSS OR NLOSS ?
loss             ;Pipe heat losses to ambient are to be included
   LEAK OR NLEAK ?
nleak            ;The system has no ducts to leak.
   HX OR NHX ?
nhx              ;No heat exchanger.
   SYSTEM DESCRIPTION COMPLETE

 ?
c1 62            ;62 suqare feet of collector specified.
 ?
c2 .90           ;FrUl of colletor.
 ?
c3 .73           ;Fr(ta)n of collector.
 ?
c9 .142          ;Incident angle modifier constant for collector.
 ?
c10 10           ;Collector fluid capacitance rate per unit area.
 ?
c12 40           ;Collector is tilted at 40 degrees.
 ?
t2 1.7           ;Collector inlet pipe (UA).
 ?
t3 1.7           ;Collector outlet pipe (UA).
 ?
s1 10.77         ;Preheat tank capacitance per unit area.
```

```
  ?
s2 1.9           ;Preheat tank height to diameter ratio.
 ?
s3 0.88          ;Preheat tank insulation loss coefficient.
 ?
s4 70            ;Preheat tank environmental temperature.
 ?
s5 6.25          ;Auxiliary tank (UA).
 ?
s6 70            ;Auxiliary tank environmental temperature.
 ?
a3 2             ;Auxiliary heat source is electricty.
 ?
a4 1             ;Electric element firing efficiency is 100%
 ?
e2 2             ;Request comparison with economics of reference system.
 ?
e7 20            ;Twenty year life cycle analysis.
 ?
e8 3100          ;Installed cost of entire system.
 ?
e11 5            ;Five year loan.
 ?
e12 0            ;No down payment.
 ?
e13 12           ;12% intrest on loan.
 ?
e14 0            ;No resale value.
 ?
e19 0            ;Solar equipment is exempt from property tax.
 ?
e21 24           ;Wisconsin state tax credit is 24% on retrofits.
 ?
e22 10000        ;Up to $10,000 of system cost is elgibile for tax credits.
 ?
e23 0            ;Wisconsin 1980 credits are single tier.
 ?
list all         ;List out all parameters and check values.

COLLECTOR PARAMETERS
 C1. COLLECTOR AREA ................................   62.00 FT2
 C2. FR-UL PRODUCT .................................    0.90 BTU/HR-FT2-DEG F
 C3. FR-TAU-ALPHA (NORMAL INCIDENCE) ...............    0.73
 C6. NUMBER OF COVERS (IF 0, C15 IS USED)...........    2.00
 C7. INDEX OF REFRACTION ...........................    1.53
 C8. EXTINCTION COEFFICIENT X LENGTH (KL)...........    0.04
 C9. INC. ANGLE MOD. CONSTANT (IF 0, C6-C8 USED).....    0.14
 C10. COLLECTOR FLOW RATE * SPECIFIC HEAT/AREA ......   10.00 BTU/HR-FT2-DEG F
 C12. COLLECTOR SLOPE ..............................   40.00 DEGREES
 C13. COLLECTOR AZIMUTH ............................    0.0  DEGREES
 C14. GROUND REFLECTANCE ...........................    0.20
 C15. INCIDENCE ANGLE MODIFIERS (10,20,30,'40,50,60,70,80 DEG.)
      1.00  0.99  0.98  0.95  0.90  0.80  0.63  0.37

COLLECTOR-STORE TRANSFER PARAMETERS
 T2. UA OF COLLECTOR INLET PIPE OR DUCT ............    1.70 BTU/HR-DEG F
 T3. UA OF COLLECTOR OUTLET PIPE OR DUCT ...........    1.70 BTU/HR-DEG F
```

```
STORAGE UNIT PARAMETERS
 S1. TANK CAPACITY/COLLECTOR AREA .....................   10.77 BTU/DEG F-FT2
 S2. STORAGE UNIT HEIGHT/DIAMETER RATIO ..............    1.90
 S3. HEAT LOSS COEFFICIENT ...........................    0.88 BTU/HR-FT2-DEG F
 S4. ENVIRONMENT TEMPERATURE (-1000 FOR TENV=TAMB) ..   70.00 DEG F
 S5. HOT WATER AUXILIARY TANK UA .....................    6.25 BTU/HR-DEG F
 S6. HOT WATER AUX TANK ENVIRONMENT TEMPERATURE .....   70.00 DEG F

LOAD PARAMETERS
 L3. HOT WATER USE ...................................   80.00 GALLONS/DAY
 L4. HOT WATER SET TEMPERATURE .......................  140.00 DEG F
 L5. WATER MAINS TEMPERATURE .........................   50.00 DEG F

AUXILIARY PARAMETERS
 A3. HOT WATER AUXILIARY FUEL (1=GAS,2=ELEC,3=OIL) ..    2.
 A4. AUXILIARY WATER HEATER EFFICIENCY ..............    1.00

ECONOMIC PARAMETERS
 E1. ECONOMIC OUTPUT DETAIL (1,2 OR 3) ..............    3.00
 E2. REFERENCE OR COMPARISON SYSTEM (1 OR 2) ........    2.00
 E3. CALCULATE RATE OF RETURN (YES=1,NO=2) ..........    2.00
 E4. INCOME PRODUCING BUILDING (YES=1,2=NO) .........    2.00
 E5. DEPRC: STR,LN.=1,DC.BAL.=2,SM-YR-DGT=3,NONE=4 ..    1.00
 E6. CONSIDER FEDERAL TAX CREDITS (YES=1,2=NO) ......    1.00
 E7. LENGTH OF ANALYSIS .............................   20.00 YEARS
 E8. TAX CREDITABLE SYSTEM BASE COST ...............$ 3100.00
 E9. NON-TAX CREDITABLE SYSTEM BASE COST ...........$    0.0
 E10. ANNUAL INCREASE IN PURCHASED ENERGY DEMAND ....    0.0  %/YR
 E11. TERM OF MORTGAGE ..............................    5.00 YEARS
 E12. DOWN PAYMENT (% OF ORIGINAL INVESTMENT) .......    0.0  %
 E13. MORTGAGE ANNUAL INTEREST RATE .................   12.00 %
 E14. RESALE VALUE (% OF ORIGINAL INVESTMENT) .......    0.0  %
 E15. ANNUAL NOMINAL (MARKET) DISCOUNT RATE .........    8.00 %
 E16. EXTRA INSUR.,LISET. IN YEAR 1 (% OF ORIG.INV.)     1.00 %
 E17. ANNUAL % INCREASE IN ABOVE EXPENSES ...........    6.00 %
 E18. EFFECTIVE FEDERAL-STATE INCOME TAX RATE .......   35.00 %
 E19. TRUE PROP. TAX RATE PER $ OF ORIGINAL INVEST ..    0.0  %
 E20. ANNUAL % INCREASE IN PROPERTY TAX RATE ........    6.00 %/YR
 E21. STATE CREDIT IN TIER ONE.......................   24.00 %
 E22. STATE CREDIT TIER ONE BREAK...................$10000.00
 E23. STATE CREDIT IN TIER TWO.......................    0.0  %
 E24. STATE CREDIT TIER TWO BREAK...................$10000.00
 E25. USEFUL LIFE FOR DEPREC. PURPOSES ..............   20.00 YEARS
 E26. % OF ST. LINE DEP. RATE (DC. BAL. DEPRC.) .....  150.00 %

 TYPE LIST FLDATA FOR FUEL COSTS
 ?
title solar water heater   ;Add new title information.
 ?
run long         ;Request long form thermal performance output.
```

```
***************   FCHART  ANALYSIS   (VERSION 4.1)  *****************
 SOLAR WATER HEATER
 OTTAWA INT'L   ONT     LATITUDE 45.3

                         THERMAL PERFORMANCE

                    HT       TA    HWLOAD      QU     QLOSS FDHW
                 (MMBTU)(DEG-F)(MMBTU)   (MMBTU)(MMBTU)
          JAN     1.82     12.4     2.19      0.57     0.04 0.24
          FEB     2.22     14.9     1.98      0.73     0.13 0.31
          MAR     2.98     26.4     2.19      1.07     0.25 0.37
          APR     2.87     42.1     2.12      1.14     0.29 0.40
          MAY     3.21     54.3     2.19      1.35     0.38 0.45
          JUN     3.22     64.8     2.12      1.45     0.43 0.48
          JUL     3.40     69.3     2.19      1.60     0.49 0.51
          AUG     3.17     66.7     2.19      1.52     0.45 0.49
          SEP     2.61     58.3     2.12      1.21     0.32 0.42
          OCT     2.08     47.7     2.19      0.91     0.18 0.33
          NOV     1.16     34.5     2.12      0.42    -0.02 0.21
          DEC     1.30     18.1     2.19      0.40    -0.04 0.20
          YR     30.04     42.5    25.75     12.38     2.91 0.37

                       PURCHASED ENERGY SUMMARY

                            GAS      ELECTRIC    OIL      TOTAL
          USE (MMBTU)       0.0       16.28      0.0      16.28
          COST ($)          0.0      227.62      0.0     227.62

                LIFE CYCLE COST ANALYSIS OF CURRENT SYSTEM

         INITIAL COST OF SYSTEM          $    3100.
         DOWN PAYMENT                    $       0.
         TOTAL TAX CREDITS               $    1984.
         ANNUAL MORTGAGE PAYMENT         $     860. FOR  5 YEARS

      ****INFORMATION****  ******SYSTEM COSTS******* *ENERGY* ***INDICATORS****
       END     IN-   COMM                            TAX     NET     NET  PW OF  CUMU-
      OF YR TEREST DEPREC     LOAN MAINT       PROP CREDIT   FUEL    CASH   CASH LATIVE
 YR   PRINC   PAID DEDUCT    PAYMT & INS        TAX RESALE   COST    FLOW   FLOW     PW
  0    3100      0      0        0     0          0   1984      0   -1983  -1983  -1983
  1    2612    372      0      860    31          0    130    228     988    915  -1068
  2    2066    313      0      860    33          0    110    250    1034    886   -182
  3    1453    248      0      860    35          0     87    275    1083    860    677
  4     768    174      0      860    37          0     61    303    1139    837   1514
  5       0     92      0      860    39          0     32    333    1200    817   2331
  6       0      0      0        0    41          0      0    367     408    257   2588
  7       0      0      0        0    44          0      0    403     447    261   2849
  8       0      0      0        0    47          0      0    444     490    265   3114
  9       0      0      0        0    49          0      0    488     537    269   3383
 10       0      0      0        0    52          0      0    537     589    273   3656
 11       0      0      0        0    56          0      0    590     646    277   3933
 12       0      0      0        0    59          0      0    649     708    281   4214
 13       0      0      0        0    62          0      0    714     777    286   4500
 14       0      0      0        0    66          0      0    786     852    290   4790
 15       0      0      0        0    70          0      0    864     934    295   5084
 16       0      0      0        0    74          0      0    951    1025    299   5383
 17       0      0      0        0    79          0      0   1046    1125    304   5687
 18       0      0      0        0    83          0      0   1150    1234    309   5996
 19       0      0      0        0    88          0      0   1266    1354    314   6310
 20       0      0      0        0    94          0      0   1392    1486    319   6629
TOTAL          1199      0     4300  1139          0   2404  13036   16073   6629
PW OF TOT      1000      0     3434   483          0   2334   5046    6629

                          UNDISCOUNTED  ANNUALIZED  PRESENT WORTH
         ENERGY COST         13036          514         5046
         TOTAL  COST         16073          675         6629
```

```
                    COMPARATIVE LIFE CYCLE ECONOMICS

    **REFERENCE SYSTEM*** ***CURRENT SYSTEM**** *******SAVINGS*******
        SYSTEM   ENERGY       SYSTEM   ENERGY        NET   PW OF    CUM.
YR       COST     COST         COST     COST        SAVE    SAVE     PW
 0          0        0        -1983        0        1984    1984   1984
 1          0      360          761      228        -627    -581   1402
 2          0      396          783      250        -636    -546    856
 3          0      436          808      275        -647    -513    341
 4          0      479          836      303        -659    -484   -142
 5          0      527          867      333        -672    -457   -600
 6          0      580           41      367         172     108   -492
 7          0      638           44      403         191     111   -381
 8          0      702           47      444         211     114   -267
 9          0      772           49      488         234     117   -149
10          0      849           52      537         260     120    -29
11          0      934           56      590         288     123     93
12          0     1027           59      649         319     127    220
13          0     1130           62      714         353     130    350
14          0     1243           66      786         391     133    483
15          0     1367           70      864         433     136    620
16          0     1504           74      951         479     140    759
17          0     1654           79     1046         530     143    902
18          0     1820           83     1150         586     147   1049
19          0     2002           88     1266         648     150   1199
20          0     2202           94     1392         716     154   1353
TOTAL       0    20622         3036    13036        4554    1353
PW TOT      0     7982         1583     5046        1353

                         UNDISCOUNTED  ANNUALIZED  PRESENT WORTH
        ENERGY SAVING        7586          299         2936
        TOTAL  SAVING        4554          137         1353

        CUMULATIVE UNDISC. ENERGY SAVINGS EQUAL INCREASED
        INVESTMENT IN  13 YEARS

        CUMULATIVE UNDISC. NET SAVINGS EQUAL ZERO
        (BREAK EVEN POINT) IN  11 YEARS
```

The savings realized by adding the solar equipment have a present worth of $1353. The system provides 37% of the energy required to supply hot water to this house each year.

In terms of first year energy costs, there is a savings of $360 - $228 or $132. However, in the same year a net payment of $761 was required for purchase of the system. As a result, during the first five years of ownership the solar system shows a negative net saving over the conventional electric system. After the system has been paid off it shows increasing net savings in years 6 though 20 due to fuel price inflation. Notice the significant effect the $1983 tax credit has on the system's economics. Since this tax credit is recieved less than one year after purchase(some states pay their share immediately) it is not discounted. If the tax credit were to be subtracted from the present worth of the total savings ($1353), the savings would be wiped out.

OPTIMIZATION OF COLLECTOR AREA

It would be interesting to see if the area chosen for this system is near the economic optimum. We can call on FCHART to compute the economic optimum size of any one system component. In this case it is collector area. The collectors are available in modules of approximately 20 square feet gross area and cost $500 each. This gives a system base cost of $1600 without collectors. To determine the economic optimum collector area, we must first set the system base cost to the cost without the collectors, then enter optimization data for the collector . This is done in the following sample run in which the initial parameter values are set as they were at the end of the last run, above.

```
 ?
e8 1600                 ;Re-set system base cost.
 ?
opdata                  ;Enter optimization data.
  INDEPENDENT VARIABLE ?
c1                      ;Collector area is independent variable.
  DEPENDENT VARIABLES (UP TO 5) ?
 none                   ;No dependent variables.

  NUMBER OF DATA POINTS (2 TO 5) ?
 2                      ;Two data points are to be entered.
  ENTER 2 DATA POINTS
 0 0                    ;Collectors are $25 per square  foot.
 200 5000               ;Maximum area to be considered is 200 square feet.
  COST ELIGIBLE FOR TAX CREDITS (YES,NO)?
 yes                    ;Collector costs are tax-creditable.
  ?
 list opdata c1         ;List out the optimization data just entered.

  INDEPENDENT VARIABLE C 1
 DATA POINTS
          0.0          0.0
          2.000E+02  5.000E+03
 ?
title optimum collector area run    ;Enter title data.
 ?
opt c1                        ;Request optimization of collector area on next run.
 ?
run


****************   FCHART  ANALYSIS   (VERSION 4.1)  *****************

 OPTIMUM COLLECTOR AREA RUN

 OTTAWA INT'L   ONT      LATITUDE 45.3


          ****  LOOP AND OPTIMIZATION PARAMETERS  ****
 C1. COLLECTOR AREA ................................  114.32 FT2


                           THERMAL PERFORMANCE

                 HT      TA   HWLOAD      QU    QLOSS FDHW
              (MMBTU)(DEG-F)(MMBTU)  (MMBTU)(MMBTU)
          JAN    3.36   12.4    2.19     0.97    0.26 0.32
          FEB    4.10   14.9    1.98     1.22    0.42 0.40
          MAR    5.49   26.4    2.19     1.75    0.68 0.49
          APR    5.30   42.1    2.12     1.84    0.74 0.52
          MAY    5.93   54.3    2.19     2.16    0.90 0.57
          JUN    5.94   64.8    2.12     2.30    0.99 0.62
          JUL    6.26   69.3    2.19     2.52    1.10 0.65
          AUG    5.84   66.7    2.19     2.41    1.04 0.63
          SEP    4.81   58.3    2.12     1.95    0.80 0.54
          OCT    3.83   47.7    2.19     1.48    0.54 0.43
          NOV    2.13   34.5    2.12     0.70    0.13 0.27
          DEC    2.40   18.1    2.19     0.68    0.11 0.26
          YR    55.39   42.5   25.75    19.98    7.68 0.48


                       PURCHASED ENERGY SUMMARY

                           GAS     ELECTRIC    OIL       TOTAL
          USE (MMBTU)      0.0      13.46      0.0       13.46
          COST ($)         0.0     188.18      0.0      188.18


              LIFE CYCLE COST ANALYSIS OF CURRENT SYSTEM

         BASE COST OF SYSTEM              $   1600.
         COST ABOVE BASE COST             $   2858.
         TOTAL COST OF SYSTEM             $   4458.
         DOWN PAYMENT                     $      0.
         TOTAL TAX CREDITS                $   2853.
         ANNUAL MORTGAGE PAYMENT          $   1237. FOR  5 YEARS
```

```
    ****INFORMATION****  ******SYSTEM COSTS******* *ENERGY* ***INDICATORS****
     END    IN-   COMM                              TAX    NET    NET  PW OF  CUMU-
  OF YR TEREST DEPREC   LOAN MAINT   PROP CREDIT   FUEL   CASH   CASH LATIVE
Y  PRINC   PAID DEDUCT  PAYMT & INS    TAX RESALE   COST   FLOW   FLOW     PW
 0   4458      0      0      0     0      0   2853      0  -2852  -2852  -2852
 1   3756    535      0   1237    45      0    187    188   1282   1187  -1665
     2970    451      0   1237    47      0    158    207   1333   1143   -522
     2090    356      0   1237    50      0    125    228   1390   1103    580
     1104    251      0   1237    53      0     88    250   1452   1068   1648
 5      0    133      0   1237    56      0     46    276   1522   1036   2684
 6      0      0      0      0    60      0      0    303    363    229   2912
        0      0      0      0    63      0      0    333    397    231   3144
        0      0      0      0    67      0      0    367    434    234   3378
        0      0      0      0    71      0      0    403    474    237   3616
10      0      0      0      0    75      0      0    444    519    240   3856
        0      0      0      0    80      0      0    488    568    244   4100
        0      0      0      0    85      0      0    537    622    247   4346
        0      0      0      0    90      0      0    591    680    250   4596
14      0      0      0      0    95      0      0    650    745    254   4850
15      0      0      0      0   101      0      0    715    815    257   5107
        0      0      0      0   107      0      0    786    893    261   5368
        0      0      0      0   113      0      0    865    978    264   5632
18      0      0      0      0   120      0      0    951   1071    268   5900
19      0      0      0      0   127      0      0   1046   1173    272   6172
20      0      0      0      0   135      0      0   1151   1286    276   6448
T TAL           1726      0   6185  1640      0   3457  10779  15145   6448
P  OF TOT       1440      0   4939   695      0   3357   4172   6448

                         UNDISCOUNTED  ANNUALIZED  PRESENT WORTH
         ENERGY COST         10779         425       4172
         TOTAL  COST         15145         657       6448

                  COMPARATIVE LIFE CYCLE ECONOMICS

    **REFERENCE SYSTEM*** ***CURRENT SYSTEM**** *******SAVINGS*******
       SYSTEM   ENERGY       SYSTEM   ENERGY       NET  PW OF   CUM.
YR       COST     COST         COST     COST      SAVE   SAVE     PW
 0          0        0        -2852        0      2853   2853   2853
            0      360         1094      188      -921   -853   1999
            0      396         1126      207      -936   -802   1196
 3          0      436         1162      228      -953   -756    438
 4          0      479         1202      250      -972   -714   -276
            0      527         1247      276      -994   -676   -953
            0      580           60      303       217    137   -816
            0      638           63      333       241    141   -676
 8          0      702           67      367       268    145   -531
 9          0      772           71      403       297    149   -382
            0      849           75      444       330    153   -229
            0      934           80      488       366    157    -72
            0     1027           85      537       406    161     88
13          0     1130           90      591       450    165    253
            0     1243           95      650       498    170    423
            0     1367          101      715       552    174    597
            0     1504          107      786       611    178    775
17          0     1654          113      865       676    183    958
18          0     1820          120      951       749    187   1145
            0     2002          127     1046       828    192   1337
            0     2202          135     1151       916    197   1534
TOTAL       0    20622         4368    10779      5482   1534
PW TOT      0     7982         2278     4172      1534

                         UNDISCOUNTED  ANNUALIZED  PRESENT WORTH
         ENERGY SAVING        9843         388        3810
         TOTAL  SAVING        5482         156        1534

         CUMULATIVE UNDISC. ENERGY SAVINGS EQUAL INCREASED
         INVESTMENT IN  14 YEARS

         CUMULATIVE UNDISC. NET SAVINGS EQUAL ZERO
         (BREAK EVEN POINT) IN  12 YEARS
```

The optmized collector area of 114 square feet is nearly twice the area used in the earlier run. The previous run, with 62 square feet of collector, showed a life cycle savings of $1353 when compared with a conventional 52 gallon electric water heater, while the optimum area system shows a LCS of $1534. Since parameters C10, collector capacitance rate, and S1, storage capacitance, were not changed before this run, we should check to see what the pump flow rate and storage volume will be with the 100 square feet of collector called for here. Parameter C10 was set to 10 BTU/ft2-hr-F previously. For an area of ≈100 square feet this gives a pump flow rate of 130 gallons per hour, larger than the rate of 75 gph specified before. Also, parameter S1 was fixed at 10.77 BTU/ft2-F, giving a required tank capacity of 149 gallons at a collector area of 114 square feet.

CHAPTER 7

WEATHER DATA

The weather data handling features of FCHART are designed to allow easy and efficient access to weather data for a large number of locations without consuming massive quantities of primary computer storage. Two "data bases" are used: data for up to 10 locations are stored internally while data for additional locations are stored on magnetic disk. In order to run an analysis in any given location, data for that location must be included in the internal data base. Commands are provided as given in sections 7.2 through 7.4 to allow the user to transfer data from the external data base to the internal data base, list or modify the internal data base, and copy small sets of data to and from secondary storage.

Depending on the system under consideration, FCHART requires one or more of the following pieces of information for each location:

Location name (City and Province)
Latitude
Slope and Azimuth of solar radiation data
Monthly average daily total solar radiation
Monthly average heating degree days
Monthly average ambient temperature

The above data for 97 Canadian locations are provided with the program, with each location assigned a location number according to its position in the external data file. The internal data base contains 10 commonly used Canadian cities and Appendix B.1 provides a list of these locations.Three lists for the 97 Canadian locations and their associated numbers are included with this documentation: Appendix B.2 is arranged by city and province and Appendix B.3 alphabetically by city name, and Appendix B.4 which is a map of Canada showing the locations.

7.1 Listing Weather Data

To list the cities in the internal data base, use the command

```
LIST CITIES
```

If you want to list all data for a location in the internal data base, use

```
LIST DATA "location number"
```

For example, if Ottawa, Ontario is in the internal data base (it is among the 10 default internal data base locations), then you can list the data for Ottawa by typing

```
LIST DATA 53
```

To list only the solar radiation, ambient temperature, or degree days for a location, use

```
LIST SOLAR "location number"
LIST TAMB  "location number"
LIST DDAYS "location number"
```

7.2.1 Accessing the External Data Base

The CITIES command is used to select locations from the external data base for inclusion in the internal data base. If you want to run analyses for locations 4, 48 and 87, you can use:

```
CITIES 4, 48, 87
```

to transfer this data to the internal data base. It is best to minimize the number of times secondary storage is accessed by minimizing the number of CITIES commands used in any FCHART session. Since the internal data base can only hold data for 10 locations, no more than 10 city numbers may be included on one CITIES command. The CITIES command causes the internal data base to be overwritten; any locations not on the most recently entered CITIES command will not be accessible.

7.2.2 Selecting a City

To run the profram using a city other than the default city, you must specify the city number when you type RUN,

e.g. `RUN 90`

where 90 is Whitehorse, and 90 was previously placed in the internal data base using:

```
CITIES 90
```

7.3 Modifying the Internal Data Base

The internal data base may be modified using CHANGE or ENTER. To alter the insolation, temperature, or degree day data for any location in the internal data base, use one of the following CHANGE commands

```
CHANGE SOLAR "location number"
CHANGE TAMB  "location number"
CHANGE DDAYS "location number"
```

When you type in one of the above CHANGE commands, FCHART asks you to enter the new data for the location specified. The questions asked are taken from the series of questions discussed in the data entry example below.

If you want to add a new location to the data base, type

```
ENTER
```

A new location number will be assigned and you will be asked for the location name, latitude, etc. in whichever system of units you are currently using. This is demonstrated in the example below. Cities numbers for user-entered locations are assigned beginning with 501. Since the internal data base can only hold data for 10 cities, you cannot ENTER data if you already have 10 locations. To reduce the number of cities in the internal data base, type CITIES followed by the numbers of the locations you wish to retain.

Suppose you wish to design a water heating system for a residence in Madison, Wisconsin. Weather data for Madison is not available in the current weather data file. You must enter the latitude, radiation data, and ambient temperature data along with the city name. Since space heating loads are not considered, heating degree days are irrelevant.

In order to enter data, you must first make sure that there is space in the internal data base for an additional location. Do this by typing CITIES followed by less than 10 location numbers. Since Ottawa, Ontario and Montreal, Quebec have climates somewhat similar to Madison, you may want to use these cities for comparison. To clear the internal data base of all locations except these two Canadian cities, type

```
CITIES 53  47
```

The weather data routines ask you tc enter data in whichever system of units is currently in effect. If you wish to try this example and you are using English units, you should switch to SI by typing UNITS. After you have entered this data, you can switch back to English units and the weather data will be converted for you. Now type ENTER to begin entering Madison data. The first request by the program is

```
TYPE IN CITY NAME (18 CHARACTERS MAXIMUM)
```

The first 18 characters you type in will be used in the output table and data listings to identify your data. Since this is the first data entered since the last CITIES command, the location number is 501. Subsequent user-entered data will be numbered 502, 503, and so on. Respond to FCHART's request with

```
MADISON WI
```

The program now gives you a chance to verify that it has read in the city name properly. The question

```
RELIST LAST INPUT ?
```

requires a YES or NO answer. YES causes FCHART to print out what you have typed in and then give you a chance to type it in again if you do not like what you see. A NO answer means you are satisfied with going on. Assuming you have not misspelled Madison, type

```
NO
```

Next, you are asked

```
TYPE IN LATITUDE
```

The latitude for Madison is 43.13 degrees, so type in

```
43.13
```

In response to the question

```
RELIST LAST INPUT ?
```

answer YES to get

```
LATITUDE IS 43.13

TRY AGAIN ?
```

The question "TRY AGAIN ?" requires a YES or NO answer. If you answer YES, you will be asked to enter the latitude again. Answer NO to go on.

There are two questions for insolation data entry. The first is

```
DO YOU WISH TO ENTER TILTED SURFACE DATA ?
```

If you answer YES, you will be asked for the slope and azimuth corresponding to your data. To enter horizontal surface data for Madison, answer NO. This gives you

```
ENTER 12 VALUES OF MONTHLY AVERAGE DAILY RADIATION IN KJ/M2-DAY,
JANUARY FIRST
```

In English units, you will be asked for data in BTU/FT2-DAY. The data for Madison in SI units, beginning with January, is

```
 5847     9125    12892    15870    19784    22107
21953    19385    14747    10338     5722     4414
```

The 12 numbers required may be typed in on as many lines as you choose. As with city name and latitude, you are given the option of relisting your input. Do so if you wish.

Entry of degree days and ambient temperature data is similar to radiation data entry. You are asked to enter 12 monthly values and then given the option to relist your input. If you relist the input, you are also given the chance to enter the data again. If you discover a mistake later on, you can also re-enter data using the CHANGE command. The degree day question is

```
ENTER 12 VALUES OF MONTHLY AVERAGE DEGREE-C DAYS JANUARY FIRST
```

Since Madison degree days will not be used in the water heating analysis, just type

```
0   0   0   0   0   0   0   0   0   0   0   0
```

The ambient temperature request is

```
ENTER 12 VALUES OF MONTHLY AVERAGE AMBIENT TEMP. IN DEG. C, JANUARY
FIRST
```

Madison ambient temperatures are

```
-7   -6   0   7   13   19   21   20   15   10   1   -5
```

When you answer

```
RELIST LAST INPUT ?
```

or

```
TRY AGAIN ?
```

with NO, you will get the usual FCHART prompt

```
?
```

This indicates that you have finished entering data and another program command is required. You can now list the data you have entered with

```
LIST DATA 501
```

7.4 Saving and Retrieving the Internal Data Base

The KEEP and GET commands may be used to store the data you have typed in on mass storage (magnetic disk) and retrieve it at some later time. These commands are described in Chapter 9. To write the internal data base onto "logical unit" (file number) 25, type

```
KEEP DATA 25
```

Data saved using KEEP can then be read back using

```
GET DATA 25
```

It is important to note that KEEP will write over whatever is in the file.

CHAPTER 8

HEAT PUMPS AND HEAT PUMP DATA

When you select a heat pump as either a delivery device or space heating auxiliary, your parameter list will include a "heat pump number". Heat pump numbers refer to heat pump data sets which are stored in the heat pump data base. Performance data for up to 5 heat pumps may be stored in the data base. Commands are provided for listing, entering, and changing heat pump data and for copying data to or from secondary storage (e.g. magnetic tape or disk).

The following information is used to identify and characterize each heat pump:

- Heat Pump Number and Name
- Units of Data (SI, English, or Mixed)
- Number of data points
- Data points, each consisting of
  - Evaporator Temperature
  - Rate of Energy Absorbed
  - Capacity
  - Work

The operating characteristics of a heat pump at a fixed condenser inlet temperature are described by a series of data points. Each data point gives the rate at which energy is absorbed, the rate of energy delivery (capacity), and the electric work required at a given inlet temperature to the heat pump evaporator. At least 2 and no more than 20 data points may be used for each heat pump. When the heat pump evaporator temperature is between two data points, the energy rates are determined by linear interpolation. Default heat pump characteristics for a 3-ton air-to-air heat pump are supplied as heat pump data set 1. The default data for heat pump number 2 represent a 3-ton water-to-air heat pump.

8.1 Listing Heat Pump Data

To list the numbers and names of the heat pumps stored in the heat pump data base, use the command

```
LIST HPDATA
```

If you want to list the data entered for a specific heat pump, use

```
LIST HPDATA "heat pump number"
```

For example, to list the data stored under heat pump number 1, type

```
LIST HPDATA 1
```

8.2 Entering Heat Pump Data

The command HPDATA is used to enter new heat pump data. When HPDATA is typed in, FCHART asks for the heat pump number, name, system of units, and so on. Since the heat pump data base is only large enough for 5 heat pumps, the heat pump number must be between 1 and 5. If you specify a number which corresponds to data which has already been stored, the existing data will be written over; only the newly entered data will be accessible.

8.2.1 Example

This example demonstrates how HPDATA is used to enter data for a 3 ton Lennox Air-to-Air heat pump. To begin, type

```
HPDATA
```

The program returns with

```
ENTER HP DATA SET NUMBER AND NAME(20 CHARACTERS MAXIMUM).
```

To avoid obliterating the default heat pump data sets, this new data should be entered as heat pump data set 3. Answer

```
3  LENNOX AIR-TO-AIR
```

The next question is

```
WHICH UNITS WOULD YOU LIKE TO USE(SI,ENG,MIXED)?
```

Since the data we have is in SI units, answer SI. Energy rates are expressed in watts in SI and BTU/hr in the English system of units. The "mixed" system of units uses absorbed energy and capacity in BTU/hr and compressor work in watts. The next question asks you how many data points you wish to use to describe the heat pump.

```
HOW MANY EVAPORATOR TEMPERATURE DATA POINTS
WILL BE ENTERED(UP TO 20 ALLOWED)?
```

There will be 6 data points used in this example. After you answer 6, you are given the opportunity to list the information you have entered so far.

```
RELIST HEAT PUMP DATA SET INFORMATION?
```

You may want to answer YES if you think you have made a mistake or if you have a basic distrust of computers. If you answer YES, you will be asked "TRY AGAIN?". This means "would you like to try entering the heat pump information again?" and requires a yes or no answer. When you respond with NO, you get

```
ENTER HEAT PUMP DATA POINTS IN THE FOLLOWING SEQUENCE,
WITH EVAPORATOR TEMPERATURES IN ASCENDING ORDER:

EVAP. TEMP.  ABSORBED ENERGY   CAPACITY   COMP. WORK
 (DEG C)         (WATTS)       (WATTS)      (WATTS)
```

The headings indicate the required order for the energy rates which make up each data point. The data points for the example Lennox heat pump are

```
    -20            810         3600        2790
    -10           2250         5700        3450
      0           4110         8220        4110
      5           5540         9900        4360
     10           7060        11760        4700
     20           8790        14280        5490
```

The first data point, for example, means that if the evaporator temperature is -20 degrees C, then when the heat pump operates, energy will be absorbed at a rate of 810 watts, energy will be delivered to the heated space at a rate of 3600 watts, and the heat pump will require work input at a rate of 2790 watts. After you have typed in the data points, FCHART asks

```
RELIST HEAT PUMP DATA?
```

This question, which requires a YES or NO answer, gives you an opportunity to get a listing of the heat pump data you have entered. If you answer YES, you will also be asked

```
WOULD YOU LIKE TO MAKE ANY CHANGES?
```

To change the heat pump work in the first data point to 3000, for example, you would answer YES. Then, when asked

```
ENTER DATA POINT NUMBER AND NEW VALUES
```

respond with

```
1       -20            810         3600        3000
```

When you are done making changes, answer <u>NO</u> to the final question

```
ANY MORE CHANGES?
```

You will then get the usual FCHART prompt

```
?
```

and you can type LIST HPDATA 3 to list the new heat pump data or use any other command you wish.

8.3 Modifying Heat Pump Data

Individual data points in an existing set of heat pump performance data may be modified using the CHANGE command. To modify the data for any heat pump, type

```
CHANGE HPDATA "heat pump number"
```

You are then asked for the number of the data point you would like to change and for the value you want

```
ENTER DATA POINT NUMBER AND NEW VALUES
```

An example response is presented in the preceeding section; data points are changed in the same manner whether the data is new or not.

8.4 Saving and Retreiving Heat Pump Data

The KEEP and GET commands may be used to store the data you have typed in on mass storage (magnetic disk) and retreive it at some later time. These commands are described in Chapter 9. To write the 5 heat pump data sets onto a storage area accessible as "logical unit" ("file number")30 , type

```
KEEP HPDATA 30
```

Data saved using KEEP can then be read back using

```
GET HPDATA 30
```

CHAPTER 9

USING FILES WITH FCHART (KEEP AND GET)

Since FCHART is most conveniently used interactively, most input of system data is from an interactive terminal. Users generally enter information into the program, following the questions provided, without storing this information in any reusable form. The KEEP command allows information to be saved on secondary storage; the companion command GET will retrieve this data whenever desired. Together, these commands can be used to save system data from one terminal session to the next. They are also useful for switching between various system descriptions, sets of weather data, optimization data, or heat pump performance specifications during a single session.

Both KEEP and GET require a "file number" (also called a "logical unit number") to be specified. The numbers typed in are used in FORTRAN READ and WRITE statements to read from or write to secondary storage (magnetic disk). Currently a "file number" is arbitrarily assigned for each of the data groups to save on and retrieve from the secondary storage device. Since changing these numbers and/or adding new numbers requires setting up of new operating procedures for different service bureaux, the users are urged to contact the respective technical representative for further information.

There are four KEEP commands and four GET commands using assigned file numbers:

```
KEEP 20
KEEP DATA 25
KEEP HPDATA 30
KEEP OPDATA 35

GET 20
GET DATA 25
GET HPDATA 30
GET OPDATA 35
```

Each KEEP command will write data into the file specified. In doing so, it will effectively erase whatever was in the file before. As a result, you will need a separate file for each set of information you wish to save. To keep both weather data and heat pump data, for example, you will need two storage areas.

The first KEEP command writes the system description, parameter values, and fuel costs into the file specified. This information is retrieved using the first GET command.

The second KEEP command, KEEP DATA, is used to store the "internal weather data base" (see Chapter 7) on mass storage. This is particularly useful when the internal data base contains user-entered data. The second GET command, GET DATA, is used to read a file written with KEEP DATA.

The third form, KEEP HPDATA, stores the heat pump data base (see Chapter 8) in the specified storage area. Since the heat pump data base only has room for data for 5 heat pumps, this is useful when a greater number of heat pumps are considered. It also saves one from having to type in the same heat pump data on different occasions. GET HPDATA will retrieve heat pump data.

The fourth form, KEEP OPDATA and GET OPDATA, will write and read optimization data (see Chapter 4). These are analagous to the other KEEP and GET COMMANDS.

Examples

(1) To save a system description, parameter values, and fuel costs in a file accessible as "logcal unit" 20, type

```
KEEP 20
```

This information may be retrieved later, provided that file 20 still exists, using

```
GET 20
```

(2) After you have typed in heat pump performance data, you will probably want to save it for future use. If you have space on mass storage accessible as file number 30, you can do this using

```
KEEP HPDATA 30
```

Then, the next time you use FCHART, you can read this data back into the program by typing

```
GET HPDATA 30
```

SECTION 3 - THERMAL ANALYSIS METHODS

CHAPTER 10

ANALYSIS OF ACTIVE SOLAR HEATING SYSTEMS

FCHART uses several methods for predicting the performance of active solar heating systems. In all cases, system performance is estimated at monthly time intervals, using equipment characteristics and weather data. This chapter provides a brief review of these design methods and their corresponding assumptions and limitations. There are four main sections. The first deals with determination of collector parameters and weather information necessary for the design methods. In the second and third sections, the design methods for liquid-based and air-based solar heating systems are presented. The fourth section is concerned with the loads and auxiliary energy consumption.

10.1 Collector Parameters and Inputs

The design methods for liquid-based and air-based solar heating systems require collector parameters and monthly average weather data as inputs. Collector characteristics determined from test results must be modified to account for variations in test procedures, insolation incidence angles, and inefficiencies in the transfer of energy from the collector to storage. The monthly incident radiation and fraction of this incident radiation that is useful for thermal collectors are essential inputs which are calculated as a function of measured data and collector parameters. In this section, the procedures for preparing collector inputs for use in the design methods as functions of known quantities are presented.

10.1.1 Collector Test Data

Standard Test Results

The rate of useful energy gain, $\dot{Q}_u$, of many collector types can be modeled according tothe Hottel-Whillier (1) equation given as

$$Q_u = F_R A_C [G_T (\tau\alpha) - U_L (T_i - T_a)] \qquad (10.1)$$

where,

A_C	is the collector area
F_R	is the heat removal efficiecy factor
G_T	is the instantaneous radiation incident upon the collector surface (per unit area)
$(\tau\alpha)$	is the transmittance-absorptance product (optical efficiency for concentrators)
U_L	is the collector loss coefficient
T_i	is the collector inlet temperature
T_a	is the ambient temperature

Equation 10.1 can be written in terms of efficiency, η, as

$$\eta = \frac{Q_u}{A_C G_T} = F_R(\tau\alpha) - F_R U_L \frac{(T_i - T_a)}{G_T} \qquad (10.2)$$

ASHRAE collector test results (2) are presented as straight line plots of η vs. $(T_i - T_a)/G_T$ with intercept $F_R(\tau\alpha)$ and slope $-F_R U_L$. Tests are performed at mid-day on clear days such that the transmittance-absorptance product is nearly the normal incidence value, $(\tau\alpha)_n$. The collector parameters $F_R(\tau\alpha)_n$ and $F_R U_L$ are specified by an FCHART user. Variations in $F_R(\tau\alpha)$ for other than normal incidence angles are accounted for as outlined in section 10.1.3. The parameter $F_R U_L$ is assumed to be constant.

User Modifications for Non-Standard Test Conditions

Thermal test data may be presented in forms other than plots of η vs. $(T_i - T_a)/G_T$. Another common form is to plot η vs. $(T_{av} - T_a)/G_T$, where T_{av} is the average of collector inlet and outlet temperatures. In this case, the straignt line equation for efficiency is

$$\eta = a - b \frac{(T_{av} - T_a)}{G_T} \qquad (10.3)$$

The intercept and slope, a and b, can be corrected to obtain $F_R(\tau\alpha)_n$ and F_RU_L as

$$F_R(\tau\alpha)_n = a \frac{\dot{m}Cp/A_c}{\dot{m}Cp/A_c + b/2} \tag{10.4}$$

$$F_RU_L = b \frac{\dot{m}Cp/A_c}{\dot{m}Cp/A_c + b/2} \tag{10.5}$$

where $\dot{m}Cp$ is the capacitance rate of the working fluid.

Air heater test data are sometimes presented as plots of η vs. $(T_o-T_a)/G_T$, where T_o is the collector outlet temperature. The intercept a' and slope b' of these results can be converted to standard parameters as follows:

$$F_R(\tau\alpha)_n = a' \frac{\dot{m}Cp/A_c}{\dot{m}Cp/A_c + b'} \tag{10.6}$$

$$F_RU_L = b' \frac{\dot{m}Cp/A_c}{\dot{m}Cp/A_c + b'} \tag{10.7}$$

If a liquid collector is to be used at a collector flow rate other than that corresponding to the test conditions for which efficiencies were measured, $F_R(\tau\alpha)_n$ and F_RU_L should be corrected as

$$F_R(\tau\alpha)_n|_{use} = F_R(\tau\alpha)_n \text{ test } \frac{r|_{use}}{r|_{test}} \tag{10.8}$$

$$F_RU_L|_{use} = F_RU_L|_{test} \frac{r|_{use}}{r|_{test}} \tag{10. 9}$$

with r determined by

$$r = \frac{\dot{m}Cp}{A_cF'U_L}\left[1 - \exp(A_cF'U_L/(\dot{m}Cp)\right] \tag{10.10}$$

where,

F' is the collector efficiency factor

In order to use equations (10.8) and (10.9), it is necessary to estimate $F'U_L$. For the test conditions, $F'U_L$ can be calculated from F_RU_L as

$$F'U_L = \frac{\dot{m}Cp}{A_c} \ell n \left(1 - \frac{F_R U_L A_c}{\dot{m}Cp}\right) \qquad (10.11)$$

This procedure neglects changes in F' from test to use conditions and does not work well for air collectors.

10.1.2 Utilizability

Utilizability is a statistical weather parameter defined as the fraction of radiation incident upon a surface during a specified period of time which is above a fixed level. Monthly average utilizability is an essential parameter in the design methods for liquid-based solar systems presented in sections 10.2.1 and 10.2.2. Two correlations for monthly average utilizability are employed in FCHART for flat-plate and concentrating collectors.

Flat-Plate Collectors

For flat-plate collectors, Klein (3) has defined monthly average utilizability as the fraction of the radiation incident upon a collector surface over a month which is above a fixed critical level. Thus,

$$\bar{\phi} = \frac{\int^{\text{month}} (G_T - G_c)^+ \, dt}{\bar{H}_T N} \qquad (10.12)$$

where,

$\bar{\phi}$ is the monthly average utilizability based upon the total incident radiation

$\bar{H}_T$ is the monthly average daily radiation incident upon the collector surface

N is the number of days in the month

G_c is the critical level of radiation necessary for net useful energy collection on an instantaneous basis

The superscript + is used to indicate that only positive values are considered in the integral.

From the Hottel-Whillier equation, it can be shown that the critical level necessary for net energy collection is

$$G_c = \frac{F_R U_L (T_i - T_a)}{F_R (\tau\alpha)} \qquad (10.13)$$

For a constant or properly averaged critical level, the monthly useful energy gain of a flat-plate collector is expressed as

$$Q_u = A_c F_R(\overline{\tau\alpha}) H_T N \tag{10.14}$$

where $F_R(\overline{\tau\alpha})$ is the collector intercept efficiency corrected for non-normal solar incidence as outlined in section 10.1.4.

Klein, using previous results of Whillier (4) and Liu and Jordan (5), developed a correlation for $\overline{\phi}$ for south facing surfaces that was used in FCHART 4.0. A more general method, applicable for any orientation is to determine $\overline{\phi}$ from hourly utilizability as outlined by Clark (6). This procedure is incorporated in versions of FCHART beyond 4.0.

The ambient temperature used to evaluate the critical level in equation (10.13) is the monthly average daytime ambient temperature. FCHART uses an average determined by integrating a correlation for long-term average diurnal temperature variation (7) over the daylight hours.

Concentrating Collectors

Collares-Pereira and Rabl (8) define monthly average utilizability as the fraction of the radiation incident upon a surface which is above a fixed critical level over the period of time in the month that the collector operates. For a properly averaged critical level, the useful energy collection is

$$Q_u = A_c F_R(\overline{\tau\alpha}) \overline{H}_{COLL} \phi_R N \tag{10.15}$$

where,

ϕ_R	is monthly average utilizability based upon incident radiation when the collector operates
$\overline{H}_{COLL}$	is the monthly average daily radiation incident upon the aperture area when the collector operates

Collares-Pereira and Rabl have developed relationships for $\overline{H}_{COLL}$ and ϕ_R for flat-plates, concentrators with fixed aperture, and 1-axis and 2-axis tracking concentrators. Their expressions for concentrating collectors are employed in FCHART. However, the monthly average utilizability is redefined based upon total radiation incident upon the collector as

$$\overline{\phi} = \phi_R \overline{H}_{COLL} / \overline{H}_T \tag{10.16}$$

10.1.3 Estimating $\overline{H}_T$

The monthly average daily radiation per unit area incident upon a tilted surface is

$$\overline{H}_T = \overline{R} \cdot \overline{H} \tag{10.17}$$

where,

$\overline{R}$ is the ratio of radiation on a tilted surface to that on a horizontal surface for an average day

$\overline{H}$ is the monthly average daily radiation on a horizontal surface

Assuming diffuse and ground-reflected radiation to be isotropic, the relationship for $\overline{R}$ is written

$$\overline{R} = \frac{\int [G_b R_b + G_d(\frac{1+\cos\beta}{2}) + \rho(\frac{1-\cos\beta}{2})]\,dt}{\int G dt} \tag{10.18}$$

where,

β is the collector slope

ρ is the ground reflectance

G is the total instantaneous horizontal radiation

G_b is the beam component of instantaneous radiation on a horizontal surface

G_d is the diffuse component of instantaneous horizontal radiation

R_b is the ratio of instantaneous beam radiation on a tilted surface to that on a horizontal surface

The factor $\overline{R}$ is determined in FCHART by evaluating equation (10.18) over an average day using numerical integration. Statistical relationships based upon day length, average daily horizontal radiation, and the monthly-average diffuse radiation fraction are used to estimate the instantaneous values of the horizontal beam and diffuse radiation. The monthly-average diffuse fraction $\overline{H}d/\overline{H}$, is calculated according to a correlation by Erbs (9). The equation for R_b is

$$R_b = \cos\theta/\cos\theta_z \tag{10.19}$$

where,

θ is the incidence angle for beam radiation

θ_z is the zenith angle; the incidence angle for a horizontal surface.

The determination of θ and θ_z is outlined in Solar Engineering of Thermal Processes (10). This publication also provides a good summary of the estimation of hourly radiation from daily data.

10.1.4 Estimating $F_R(\overline{\tau\alpha})$

In terms of the intercept of the collector efficiency curve, the product of the collector heat removal efficiency factor and the monthly-average transmittance-absorptance product is determined as

$$F_R(\overline{\tau\alpha}) = F_R(\tau\alpha)_n \quad \frac{(\overline{\tau\alpha})}{(\tau\alpha)_n} \tag{10.20}$$

where,

$(\overline{\tau\alpha})/(\tau\alpha)_n$	is the ratio of monthly average transmittance-absorptance product to the transmittance-absorptance product at normal incidence

The monthly-average transmittance-absorptance product of a collector is the ratio of the monthly total radiation absorbed by the collector surface to the incident radiation. Thus

$$\frac{(\overline{\tau\alpha})}{(\tau\alpha)_n} = \frac{\int^{\text{month}} [G_b R_b \cdot \frac{(\tau\alpha)_b}{(\tau\alpha)_n} + G_d F_{sky} \frac{(\tau\alpha)_d}{(\tau\alpha)_n} + \rho G F_{gnd} \frac{(\tau\alpha)_r}{(\tau\alpha)_n}]dt}{\overline{H}_T N} \tag{10.21}$$

where,

$\frac{(\tau\alpha)_b}{(\tau\alpha)_n}, \frac{(\tau\alpha)_d}{(\tau\alpha)_n}, \frac{(\tau\alpha)_r}{(\tau\alpha)_n}$	are the instantaneous transmittance-absorptance product ratios for beam, diffuse, and reflected solar radiation
F_{sky}, F_{gnd}	are the view factors from the receiver to the sky and ground, respectively

The parameters $(\tau\alpha)_d/(\tau\alpha)_n$, $(\tau\alpha)_r/(\tau\alpha)_n$, F_{sky}, F_{gnd}, and ρ are considered to be constants such that equation (10.21) can be written

$$\frac{(\overline{\tau\alpha})}{(\tau\alpha)_n} = \frac{\int^{\text{month}} G_b R_b \frac{(\tau\alpha)_b}{(\tau\alpha)_n}}{\overline{H}_T N} + \frac{\overline{H}_d}{\overline{R} \cdot \overline{H}} F_{sky} \frac{(\tau\alpha)_d}{(\tau\alpha)_n} + \frac{\rho}{\overline{R}} F_{gnd} \frac{(\tau\alpha)_r}{(\tau\alpha)_n} \tag{10.22}$$

The first term of equation (10.22) is evaluated using numerical integration over an average day of the month as suggested by Klein (11). The equations for the transmittance-absorptance product ratios for beam, diffuse, and ground reflected radiation and the view factors from the receiver to the sky and the ground are dependent upon the collector type as outlined below. The ground reflectance is a user specified collector parameter which may vary by month.

Flat-Plate Collectors

For flat-plate collectors, $(\tau\alpha)_b/(\tau\alpha)_n$ can be approximated from ASHRAE test results (2) as

$$\frac{(\tau\alpha)_b}{(\tau\alpha)_n} = 1 - b\left(\frac{1}{\cos\theta} - 1\right) \tag{10.23}$$

where,

θ is the angle of incidence

b is a constant

The user specifies a value of b as a collector parameter. Equation (10.23) is used when b is non-zero. If a value of b of zero is specified, then $(\tau\alpha)_b/(\tau\alpha)_n$ is determined as

$$\frac{(\tau\alpha)_b}{(\tau\alpha)_n} = \frac{\tau\cdot\alpha}{[1 - (1-\alpha)]\rho_d}\cdot\frac{1}{(\tau\alpha)_n} \tag{10.24}$$

where,

τ is the transmittance of the cover system to beam radiation

α is the absorptance of the collector surface

ρ_d is the reflectance of the cover system for diffuse radiation

The transmittance of the cover system to beam radiation at a known incidence angle is determined by calculating the reflectance and absorptance of the covers using the Fresnel equation and Bouger's law as described in Solar Engineering of Thermal Processes (10). The angular dependence of the absorptance of the absorbing surface is determined using an empirical fit to measurements taken by Hottel and Woertz (1) for a non-selective blackened surface. The limited data suggests that selective surfaces may exhibit similar behavior (12).

For flat-plate collectors, $(\tau\alpha)_d/(\tau\alpha)_n$ is approximated by the value corresponding to that for beam radiation at an incidence angle of 60 degrees (1,13, 14). The transmittance-absorptance product ratio for ground-reflected radiation can be determined in a similar manner. The ground is assumed to be a diffusely reflecting surface having a reflectance of ρ. With these assumptions Brandemuehl and Beckman (14` have correlated the mean incidence angle, $\overline{\theta}_r$, for which $(\tau\alpha)_r/(\tau\alpha)_n$ is equal to $(\tau\alpha)_b/(\tau\alpha)_n$ as

$$\overline{\theta}_r = 89.8° - 0.57883\beta + 0.002693\beta^2 \tag{10.25}$$

The view factor of the sky for flat-plate collectors is

$$F_{sky} = \frac{1 + \cos\beta}{2} \tag{10.26}$$

while the ground view factor is given as

$$F_{gnd} = \frac{1 - \cos\beta}{2} \tag{10.27}$$

Concentrating Collectors

The available test results for concentrating collectors (15) indicate that $(\tau\alpha)_b/(\tau\alpha)_n$ cannot be represented according to equation (10.23). It therefore becomes necessary to provide data for incidence angle modifiers. For single-axis continuously tracking collectors, the sun is always in a plane passing through the collector axis and normal to the collector aperture. For fixed CPC's, the incidence angle modifier is assumed to be constant with respect to incidence angle variations in a plane normal to the collector axis. This is probably a good assumption for CPC's with half acceptance angles less than about 20 degrees. Therefore, for both imaging collectors with single-axis tracking and CPC's, FCHART assumes that incidence angle modifier data is given as a function of incidence angle variations within a plane which passes through the collector axis and is normal to the collector aperture. For two-axis trackers, normal incidence is always assumed.

For imaging collectors, diffuse and reflected radiation are unimportant and $(\tau\alpha)_d$ and $(\tau\alpha)_r$ are considered zero. For CPC collectors, $(\tau\alpha)_r$ is assumed to be zero, while $(\tau\alpha)_d$ is determined as outlined in Solar Engineering of Thermal Processes (10).

The view factor of the sky for a CPC collector is

$$F_{sky} = \frac{\sin\theta_c + \min(\sin\theta_c, \cos\beta)}{2} \tag{10.28}$$

where

θ_c is the half acceptance angle of the CPC

10.1.5 Modifiying F_RU_L and $F_R(\tau\alpha)_n$ for the Transfer Device

The three collector-store transfer options (pipe or duct losses, duct leaks, and heat exchanger effects) are accounted for by modifying F_RU_L and $F_R(\tau\alpha)_n$. This is possible since each of these transfer inefficiencies affect only collection. Each degrading influence causes the collector to perform equivalently to a less efficient collector.

Collector-Storage Heat Exchanger

To account for a heat exchanger between the collector and storage, F_RU_L and $F_R(\tau\alpha)_n$ are modified as

$$F'_RU_L = F_RU_L \cdot \frac{F'_R}{F_R} \tag{10.29}$$

$$F'_R(\tau\alpha)_n = F_R(\tau\alpha)_n \cdot \frac{F'_R}{F_R} \tag{10.30}$$

The factor F'_R/F_R has been analytically derived by deWinter (16) and is given by

$$\frac{F'_R}{F_R} = \left[1 + \left(\frac{A_cF_RU_L}{\dot{m}Cp}\right)\left(\frac{\dot{m}Cp}{\epsilon c_{min}} - 1\right)\right]^{-1} \tag{10.31}$$

where,

$\dot{m}Cp$ is the capacitance rate through the collector

ϵC_{min} is the effectiveness-minimum capacitance rate product of the heat exchanger

Pipe of Duct Heat Losses

The energy losses from ducts of pipes leading to or returing from the collector can be significant. Beckman (17) has shown that the combination of pipes or ducts plus solar collector is equivalent in thermal performance to a solar collector with different values of U_L and $(\tau\alpha)_n$. The modified values of F_RU_L and $F_R(\tau\alpha)_n$ accounting for pipe or duct losses are

$$F_RU_L' = \frac{F_RU_L\left(1 - \frac{(UA)_i}{\dot{m}Cp} + \frac{(UA)_i + (UA)_o}{A_cF_RU_L}\right]}{1 - \frac{(UA)_o}{\dot{m}Cp}} \tag{10.32}$$

$$F_R(\tau\alpha)_n' = F_R(\tau\alpha)_n/(1 + \frac{(UA)_o}{\dot{m}Cp}) \tag{10.33}$$

where,

$(UA)_i$, $(UA)_o$ are the conductances for heat loss from the collector inlet and outlet pipes or ducts

Duct Leaks

For air-based space heating systems, the collector parameters are modified to account for ambient air leaks into the collector inlet and outlet ducts using a method developed by Jones (18). The collector and associated ductwork are assumed to be under negative pressure with respect to ambient. For the situation where all leaks occur into collector inlet only, $F_R(\tau\alpha)_n$ remains unchanged, while F_RU_L is modified as

$$F_R{}^*U_L = F_RU_L(1 - L_R) + L_R \cdot \frac{\dot{m}Cp}{A_c} \tag{10.34}$$

where,

L_R is the ratio of leakage flow rate to collector outlet flow rate

If air leakage is into the outlet duct only, then F_RU_L and $F_R(\tau\alpha)_n$ are adjusted as follows:

$$F_R{}^*U_L = F_RU_L \cdot \frac{F_R{}^*}{F_R} + L_R \cdot \frac{(\dot{m}Cp)_c}{A_c} \tag{10.35}$$

$$F_R{}^*(\tau\alpha)_n = F_R(\tau\alpha)_n \cdot \frac{F_R{}^*}{F_R} \tag{10.36}$$

with $F_R{}^*/F_R$ determined as

$$\frac{F_R^*}{F_R} = \frac{(1-L_R)\dot{m}C_p}{A_cF_RU_L}\left[1-\left(1-\frac{A_cF_RU_L}{\dot{m}C_p}\right)^{\left(\frac{1}{1-L_R}\right)}\right] \tag{10.37}$$

For situations where leaks are evenly divided between inlet and outlet ducts the following expression are utilized:

$$F_R{}^*U_L = F_RU_L \cdot \frac{F_R{}^*}{F_R} \cdot \frac{1-L_R}{1-\frac{L_R}{2}} + L_R \frac{\dot{m}C_p}{A_c} \tag{10.38}$$

$$F_R{}^*(\tau\alpha)_n = F_R(\tau\alpha)_n \cdot \frac{F_R{}^*}{F_R} \tag{10.39}$$

where $F_R{}^*/F_R$ is evaluated with equation (10.37) except that $L_R/2$ is substituted for L_R.

10.2 Liquid-Based Heating Systems

The $\overline{\phi}$,f-chart method is used to determine the thermal performance of liquid-based solar heating systems in FCHART. This procedure was originally developed for closed-loop systems where the load is characterized by a single minimum useful temperature, T_{min} (19,20). For these systems, generally any temperature greater than T_{min} is sufficient to meet a significant fraction of the load. Recently, the method has been extended to open-loop systems where the load is characterized by two temperatures, the make-up (or mains) and set temperatures (21). The modified $\overline{\phi}$,f-chart procedure is general for both closed and open-loop systems. For space heating systems, the method is further generalized for short-term or long-term storage. This is accomplished by including the change in internal energy of storage in the analysis. For storage sizes characteristic of seasonal storage, this method is equivalent to a procedure presented by Braun (22). For short term storage, the change in internal energy is small and the method is essentially the $\overline{\phi}$,f-chart procedure.

10.2.1 Space Heating and Closed-Loop Processes

A schematic of the closed-loop liquid-based heating systems for which FCHART is applicable appears in Figure 10.1. Solar energy is collected by a flat-plate or concentrating collector and stored as sensible heat in a liquid storage tank. Heat is supplied from storage to the load by a delivery device if there is an energy demand and if the storage temperature is greater than a user specified minimum useful temperature, T_{min}. The delivery device can be a heat exchanger or a heat pump. If a heat pump is employed, direct solar heating occurs across a heat exchanger whenever the storage temperture is greater than T_{by}, a minimum bypass temperature for direct solar heating. Auxiliary energy is added if the delivery device cannot meet the load. Additional assumptions are as follows:

1) The inlet conditions to the load side of the delivery device (T_{Li} and $\dot{m}_{Li}$ in Figure 10.1) are constant or averages.

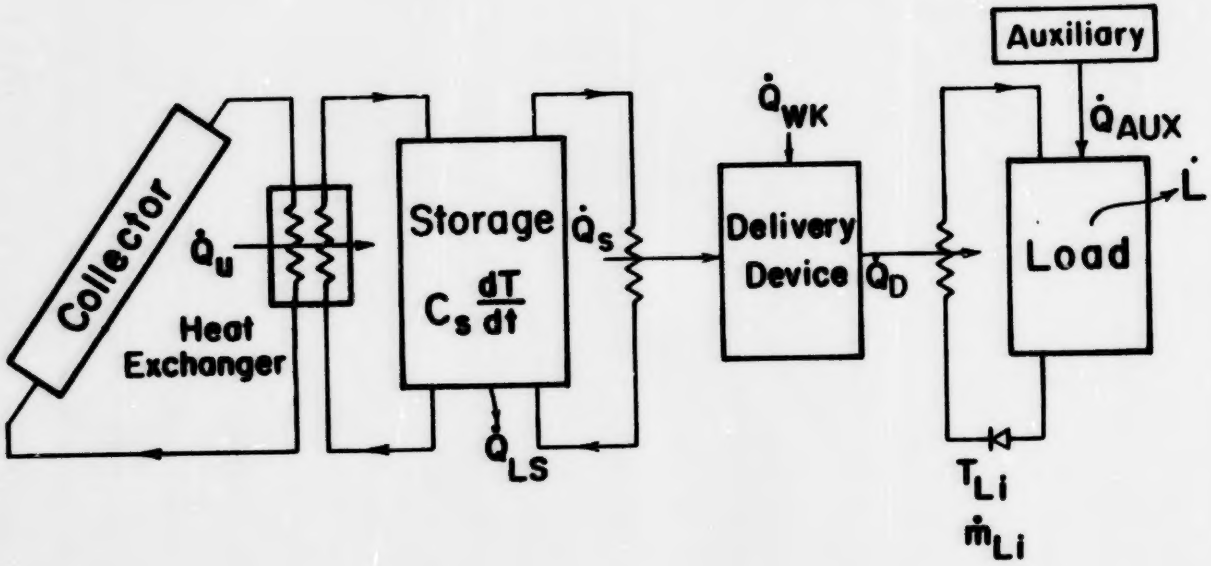

Collector
$\dot{Q}_u$
Heat Exchanger
Storage
$C_s \frac{dT}{dt}$
$\dot{Q}_s$
$\dot{Q}_{LS}$
$\dot{Q}_{WK}$
Delivery Device
$\dot{Q}_D$
Auxiliary
$\dot{Q}_{AUX}$
Load
$\dot{L}$
T_{Li}
$\dot{m}_{Li}$

Figure 10.1 Schematic of Closed-Loop Liquid-Based System

2) 7-day-a-week loads are assumed for process heating systems (not necessarily 24 hour per day).

3) The storage medium is fully-mixed.

4) No energy "boil-off" for process heating systems.

System Analysis

An instantaneous energy balance on the storage medium of Figure 10.1 is

$$C_s \frac{dT}{dt} = \dot{Q}_u^{+} - \dot{Q}_{LS} - \min(\dot{Q}_S, \dot{Q}_S|_{max}) \tag{10.40}$$

where,

C_s	is the capacitance of storage
T	is the instantaneous storage temperature
t	is time
$\dot{Q}_u$	is the rate of useful collection
$\dot{Q}_{LS}$	is the loss rate from storage
$\dot{Q}_S$	is the rate at which the delivery device can remove energy from storage
$\dot{Q}_S\|_{max}$	is the maximum rate at which energy can be supplied from storage when the delivery device meets the load

Integrating equation (10.40) over a month yields

$$\Delta U = C_S(T_F - T_I) = Q_u - Q_{LS} - Q_S \tag{10.41}$$

where

ΔU	is the monthly change in internal energy of storage
T_F	is the final monthly storage temperature
T_I	is the initial monthly storage temperature

The design method involves evaluating the terms of the energy balance of equation (10.41) on a monthly basis given system parameters, meteorlogical information, and the initial storage temperature. The energy collection, storage losses, and energy supply are calculated as functions of the average storage temperatures at which they occur. The $\bar{\phi}$,f-chart correlation provides a relation between the actual solar energy collection and the collector if the inlet temperature were equal to temperature which determines the correct energy supply.

The energy delivered to the load on a monthly basis is assumed to be the minimum of the load and the energy delivered if the delivery device operated continuously over the period of time of load occurrence. Thus,

$$Q_D = \min[\dot{Q}_D(\bar{T}_s)\Delta t, L] \tag{10.42}$$

where

Δt is the time period that the load occurs during the month (the entire month for space heating)

$\bar{T}_S$ is an average supply temperature from storage if the delivery device operated continuously whenever the load occurred

$\dot{Q}_D$ is the rate at which energy can be delivered to the load with a source temperature of $\bar{T}_S$

L is the monthly total load

If the delivery device is a heat exchanger, the energy delivered to the load is the energy supplied from storage given as

$$Q_D = Q_S = \min(\varepsilon C_{min}(\bar{T}_S - T_R)\Delta t,\ L) \tag{10.43}$$

where,

εC_{min} is the load heat exchanger effectiveness-minimum capacitance rate product

T_R is the cold side heat exchanger return temperature (room temperature for space heating)

If the delivery device is a heat pump, then the energy delivered to the load depends upon the heat pump capacity as

$$\dot{Q}_D = \min(\dot{Q}_{cap}(\bar{T}_S)\Delta t, L) \tag{10.44}$$

where,

$\dot{Q}_{cap}(\bar{T}_S)$ is the heat pump capacity evaluated at $\bar{T}_S$

For this situation, the energy supplied from storage to the load depends upon the average heat pump capacity and COP as

$$Q_S = \min(\dot{Q}_{cap}(\bar{T}_S)(1 - 1/\overline{COP}(\bar{T}_S))\Delta t,\ Q_S\big|_{max}(\bar{T}_S) \tag{10.45}$$

where,

$\overline{COP}(\bar{T}_S)$ is the coefficient of performance of the heat pump evaluated at $\bar{T}_S$

The maximum energy that can be supplied to the load from storage (i.e., the solar load) is

$$Q_S\Big|_{max} = L(1 - 1/COP(\overline{T}_S)) \tag{10.46}$$

Energy collection is determined in two ways. First, for a properly averaged critical level, the net useful energy gain of a collector is calculated as outlined in section 10.1.2 according to

$$Q_u = A_C F_R (\overline{\tau\alpha}) \overline{H}_T \, \overline{\phi}(\overline{G}_c) N \tag{10.47}$$

The average critical level, $\overline{G}_c$, is evaluated using equation (10.13) at an average collector inlet temperature, $\overline{T}_c$, and an average daytime ambient temperature, $\overline{T}_{da}$. Energy collection is also determined using the $\overline{\phi}$,f-chart correlation, which relates the actual energy collection to the energy collection that would have occurred had the average critical level been evaluated at $\overline{T}_S$. The relation is given as

$$Q_u = A_C F_R (\overline{\tau\alpha}) \overline{\phi}_{max}(\overline{T}_S) \overline{H}_T N - \text{Corr} \tag{10.48}$$

where,

$$\text{Corr} = a(e^{bf}-1)(1-e^{cX})e^{dz} Q_S\Big|_{max}$$

$a = 0.015(C_s/350 \text{ KJ/m}^2\text{-°C})^{-.76}$

$b = 3.85$

$c = -0.15$

$d = -1.959$

$f = Q_S/Q_S\Big|_{max}$

$X = A_c F_R U_L \ (100°C)\Delta t_m / Q_S\Big|_{max}$

$Z = \dfrac{L}{\varepsilon C_{min} \Delta t (100°C)}$ heat exchanger

$Z = 0$ heat pump

$\overline{\phi}_{max}(\overline{T}_S)$ is monthly average utilizability evaluated at $\overline{T}_S$

Δt_m is the length of time in the month

The losses from storage on a monthly basis are

$$Q_{LS} = (UA)_T(T-T_{env})\Delta t_m \qquad (10.49)$$

where,

$\bar{T}$ is the average storage temperature

T_{env} is the environmental temperature to which losses occur

The average storage temperature is determined from the following correlation (22).

$$\bar{T} = \bar{T}_S + g(e^{kf}-1)e^{hz} \qquad (10.50)$$

where,

$g = (0.2136°C)(C_S/350kJ/h^2-°C)^{-.704}$

$h = -4.002$

$k = 4.702$

For space heating systems, the change in internal energy is included and the final storage temperature is determined as

$$T_F = 2\bar{T} - T_I \qquad (10.51)$$

Solution of the Equations

A "bracketed form" of the secant method is used in FCHART to solve for the value of $\bar{T}_s$ which satisfies the energy balance of equation (10.41) given the initial conditions, system parameters, and the meteorological inputs. A function G is defined such that

$$G = Q_u - Q_S - Q_{LS} - \Delta U = 0 \qquad (10.52)$$

Let $\bar{T}_{S_{n-1}}$ and $\bar{T}_{S_n}$ be two successive guesses for $\bar{T}_S$. Then

$$\bar{T}_{S_{n+1}} = \bar{T}_{S_n} - \frac{G(\bar{T}_{S_n})(\bar{T}_{S_n} - \bar{T}_{S_{n-1}})}{G(\bar{T}_{S_n}) - G(\bar{T}_{S_{n-1}})} \qquad (10.53)$$

If $\bar{T}_{S_{n+1}}$ is greater than a recent maximum, $\bar{T}_{S_{max}}$, or less than a minimum, $\bar{T}_{S_{min}}$, where $G(\bar{T}_{S_{max}}) \times G(\bar{T}_{S_{min}}) < 0$, then a bisection is performed as

$$\bar{T}_{S_{n+1}} = \frac{\bar{T}_{S_{max}} + \bar{T}_{S_{min}}}{2} \qquad (10.54)$$

$\bar{T}_{S_{min}}$ and $\bar{T}_{S_{max}}$ are reset during each interation as follows:

1) If $G(\overline{T}_{S_{n+1}}) \times G(\overline{T}_{S_{max}}) < 0$, then $\overline{T}_{S_{min}} = \overline{T}_{S_{n+1}}$ and $\overline{T}_{S_{max}}$ remains unchanged.

2) If $G(\overline{T}_{S_{n+1}}) \times G(\overline{T}_{S_{min}}) < 0$, then $\overline{T}_{S_{max}} = \overline{T}_{S_{n+1}}$, and $\overline{T}_{S_{min}}$ remains unchanged.

The solution method can be summarized in the following steps:

1) With a guess of $\overline{T}_{S_n}$, calculate Q_S, Q_u, Q_{LS}, ΔU ($\Delta U = 0$ for process heating)
2) Calculate G_n, $T_{S_{n+1}}$.
3) Repeat steps 1 and 2 until $|G_n| \leq .001\ (|Q_{u_n}|+|Q_{S_n}|+|Q_{LS_n}|+|\Delta U_n|)$

If the solution to the energy balance yields an average supply temperature, $\overline{T}_S$, (T_F for space heating) which is less than the minimum allowable T_{min}, then the following steps are exercised:

1) $T_F = \overline{T}_S = T_{min}$
2) Calculate $\overline{\Phi}_{max}$
3) Guess Q_{S_n}
4) Calculate $\overline{T}$, Q_{LS}, Q_u
5) Calculate $G_n = Q_S - (Q_u - Q_{LS} - \Delta U)$
6) Determine $Q_{S_{n+1}}$ using Newton's method as: $Q_{S_{n+1}} = Q_{S_n} - G_n/(dG/dQ_S)$
7) Repeat steps 4-6 until $|G_n| \leq .001\ Q_S$

For space heating systems, boil-off is accounted for by restricting the average storage temperature to the boiling point of water. This is a good assumption, since space heating is a low temperature application in which boil-off is only significant during summer months when the load is insignificant. It is necessary to include boil-off for space heating systems to realistically model the energy storage from month to month during summer.

If the solution to the monthly energy balance yields an average storage temperature that is greater than the boiling point of water, then the following steps are exercised:

1) $T_F = \overline{T} = \overline{T}_S = T_b$

2) Calculate Q_S, Q_u, Q_{LS}

For systems with a heat pump delivery device, direct solar heating is substituted for heat pump heating whenever the average storage temperature is greater than the user specified bypass temperature. The direct solar heating mode can be eliminated by specifying a high bypass temperature.

For a yearly analysis of a space heating system, an initial storage temperature is assumed. Each end of the month temperature is used as the initial temperature of the following month. The process is repeated for as many yearly cycles as necessary to ensure that the initial and final storage temperatures are approximately the same. Two cycles are usually sufficient.

10.2.2 Open-Loop DHW Systems

An open-loop system differs from a closed-loop in that heat is extracted from storage to the load via a mass flow of fluid that ultimately leaves the system. A schematic of the open-loop system for which FCHART is applicable appears in Figure 10.2. Solar energy is supplied for water heating from collectors to a preheat tank. Auxiliary energy is added by a conventional water heater to maintain the desired set temperature. A mixing valve prevents the outlet temperature of the auxiliary from exceeding the desired set temperature. For this configuration, losses from the auxiliary tank represent a portion of the load which the solar can meet. The storage tank is assumed to be pressurized, such that no energy boil-off occurs.

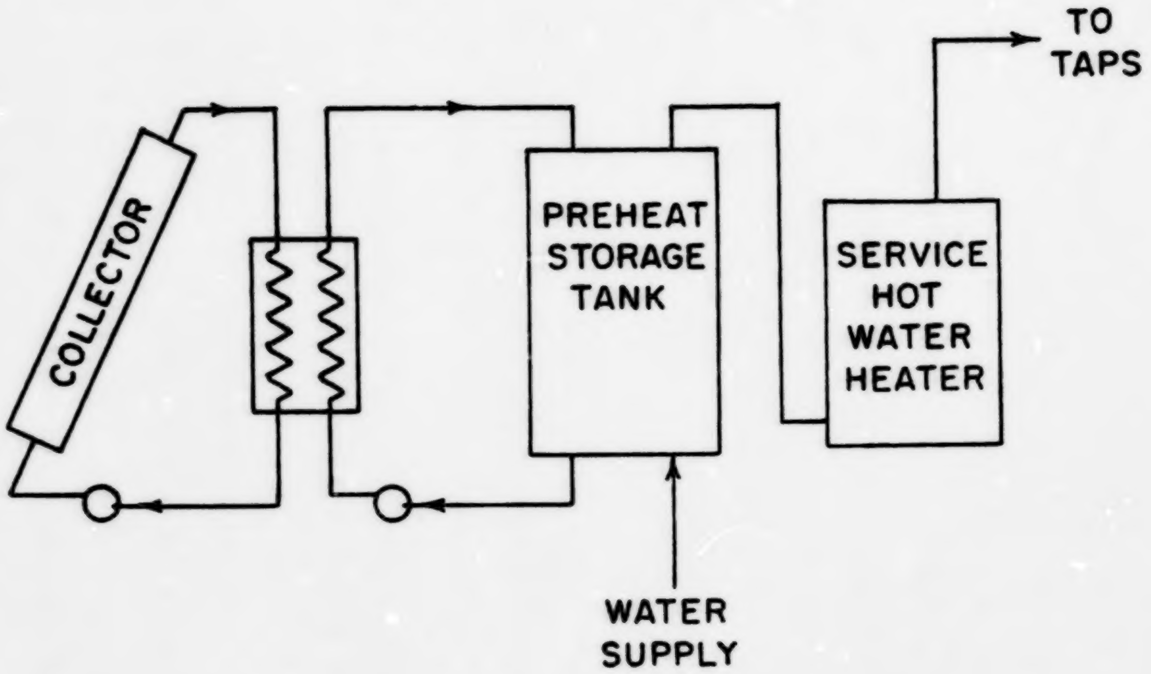

TO
TAPS
COLLECTOR
PREHEAT
STORAGE
TANK
SERVICE
HOT
WATER
HEATER
WATER
SUPPLY

Figure 10.2. Schematic of an Open-Loop DHW System

The method for open-loop systems is identical to that for closed-loop systems except for the definitions of Q_S and Z. The change in internal energy of storage is neglected so that the monthly energy balance is

$$Q_U = Q_{LS} - Q_S = 0 \tag{10.55}$$

Q_u and Q_{LS} are determined according to equation (10.48) and (10.49). The parameter Z, which is a measure of the temperature rise required by load and is required by equation (10.48), is defined for an open-loop system as

$$Z = \frac{L}{M_w C_p (100°C)} \tag{10.56}$$

where,

M_w monthly mass usage of water

C_p specific heat of water

The energy supplied from solar to the load is

$$Q_S = \min\left(M_w C_p(\overline{T}_S - T_{main}), L\right)$$

where,

T_{main} water mains temperature

T_{set} desired set temperature

Auxiliary tank losses are accounted for by modifying the water usage, M_w, such that load calculated using this new usage is equal to the sum of the original load plus the energy losses from the auxiliary tank.

The solution of equation (10.55) for T_S is identical to that for closed-loop systems outlined in secton 10.2.1 and therefore will not be discussed here.

10.2.3 Combined Space and Water Heating

A modification of the design method for closed-loop systems outlined in section 10.2.1 is employed to predict the performance of combined space and water heating systems of the type shown in Figure 10.3. The method is based upon the assumptions of both sections 10.2.1 and 10.2.2.

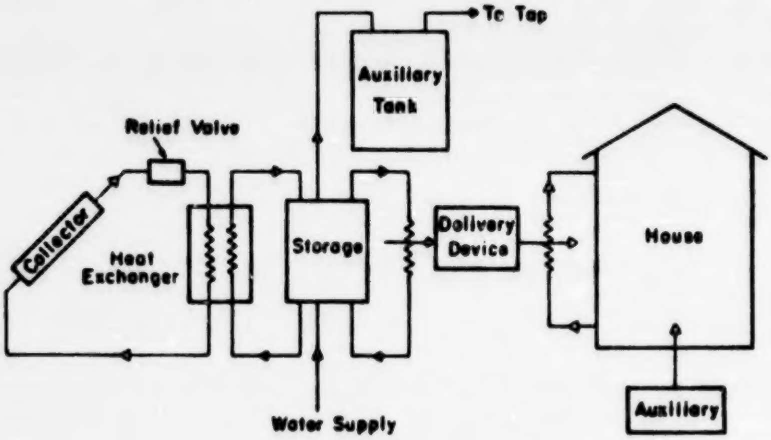

To Tap
Auxiliary Tank
Relief Valve
Collector
Heat Exchanger
Storage
Delivery Device
House
Auxiliary
Water Supply

Figure 10.3. Schematic of a Liquid-Based Combined Space and Water Heating System

The solar energy contribution to the load is the sum of the energies supplied to the heated space and the hot water system given as

$$Q_S = Q_{SH} + Q_{DHW} \tag{10.57}$$

where,

Q_{SH} is the solar energy supplied to the space heating load

Q_{DHW} is the solar energy supplied to the DHW load

The quantities, Q_{SH} and Q_{DHW}, are calculated as outlined in sections 10.2.1 and 10.2.2, respectively, at an average supply temperature, $\bar{T}_S$.

Energy collection is determined using equation (10.48). The parameter Z, required by this expression, is weighted according to the magnitude of the space and water heating loads as

$$Z = \frac{Z_{DHW} \cdot L_{DHW} + Z_{SH} \cdot L_{SH}}{L_{DHW} + L_{SH}} \tag{10.58}$$

where the subscripts DHW and SH refer domestic hot water heating and space heating only, respectively.

10.3 Air-Based Solar Heating

A schematic of the air-based space and water heating system for which FCHART is applicable appears in Figure 10.4. System operation is characterized by the following three modes:

1) Collector to load — energy is demanded by the heated space and the collector outlet temperature is greater than the room temperature.
2) Collector to storage — the collector outlet temperature is greater than the temperature at the bottom of storage and there is no space heating load.
3) Storage to load — no collection is available, energy is demanded by the heated space, and the temperature in the top of storage is greater than the room temperature.

In modes 1 and 3, auxiliary energy from a conventional furnace may supplement the solar contribution. Energy is supplied for domestic hot water by heat exchange from the hot air exiting a flat-plate collector to a preheat tank. Additional energy, if required, is added by a conventional water heater to maintain the desired set temperature. Assumptions on which the design method for air-based systems is based as follows:

1) The U value of the storage bin is assumed to be .42 W/m^2-°C.
2) Negligible temperature gradients normal to the flow direction in the storage bin.
3) Rock bed or phase change energy storage.
4) The collector air flow rate is greater than or equal to 5ℓ/s-m^2 and less than or equal to 20ℓ/s-m^2.
5) The storage capacity is greater than or equal to 157.5 KJ/m^2-°C and less than or equal to 1260 KJ/m^2-°C.

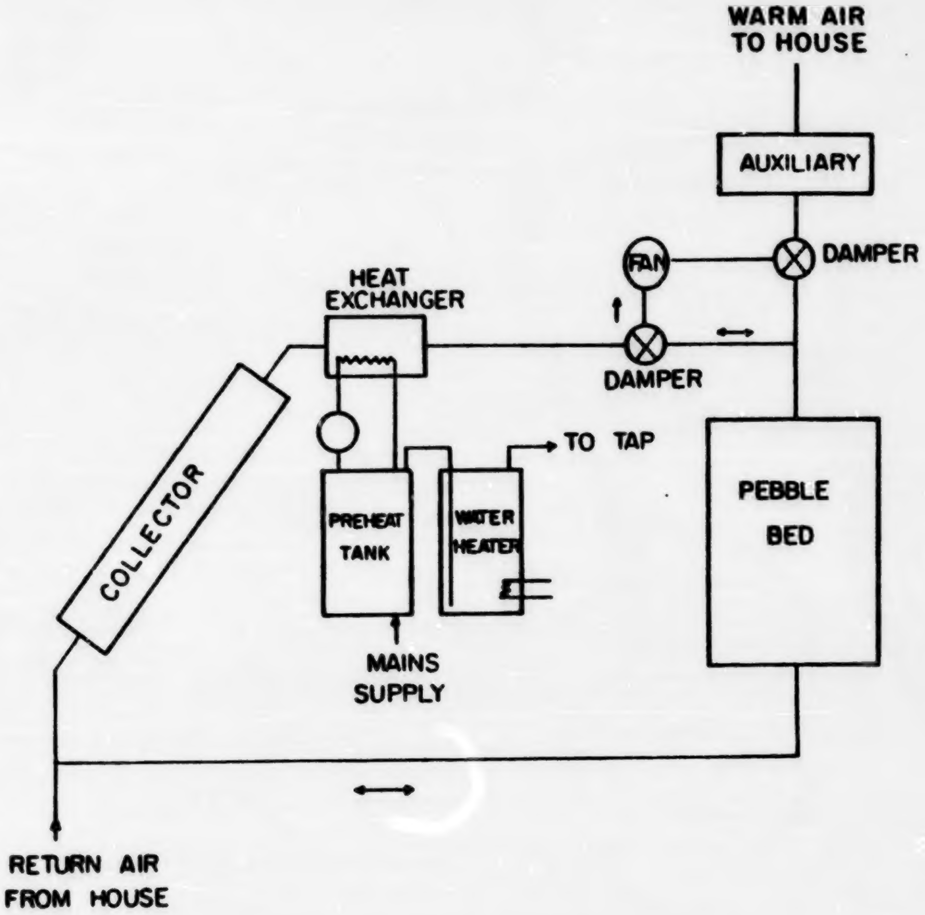

WARM AIR TO HOUSE
AUXILIARY
FAN
DAMPER
HEAT EXCHANGER
DAMPER
TO TAP
COLLECTOR
PREHEAT TANK
WATER HEATER
PEBBLE BED
MAINS SUPPLY
RETURN AIR FROM HOUSE

Figure 10.4 Schematic of an Air-Based Space and Water Heating System

Space Heating Only

The analysis of air-based space heating systems is identical to that in earlier FCHART versions, except that the method has been extended to allow phase change energy storage. The fraction of load met by solar, f, is correlated as a function of two dimensionless parameters X and Y as presented by Klein (23). The parameters X and Y are determined as

$$X = \frac{A_C F_R U_L (100°C - \bar{T}_a)\Delta t_m}{L} \qquad (10.60)$$

$$Y = \frac{A_C F_R U_L (\overline{\tau\alpha})\bar{H}_T N}{L} \qquad (10.61)$$

The correlation for f was generated for a collector air flowrate of 10.1 l/s per square meter of collector area and a storage capacity of .25 cubic meters of rock pebbles per square meter of collector area. The performance of systems having other collector air flowrates or storage capacities is estimated by modifying X according to Klein. The thermal performance of air-based space heating systems employing phase change energy storage is estimated using the FCHART correlation by defining an effective storage capacity as outlined by Jurinak (24).

Water-Heating Only

With no space heating, the system of Figure 10.4 reduces to that described in section 10.2.2 for DHW systems and the analysis presented there is applicable. To model an air collector one need only specify the appropriate collector and transfer device parameters.

Combined Space and Water Heating

The performance of the combined air-based space and water heating system of Figure 10.4 is estimated using the methods for DHW and air-based space heating systems.

The performance of the space and water heating systems are determined separately using a load for each equal to the total space and water heating load. The fraction of the total load which is non-purchased energy is calculated according to the load weighted average of these individual predictions as

$$F_{NP} = \frac{(F_{DHW} \cdot L_{DHW} + F_{SH} \cdot L_{SH})}{L_{DHW} + L_{SH}} \qquad (10.62)$$

10.4 Loads and Auxiliary

For closed-loop process heating systems, the load and number of hours of load occurrence are specified by the user on a per day basis. Open-loop DHW loads are assumed to include auxiliary storage losses and are calculated as

$$L_{DHW} = M_W C_p (T_{set} - T_{main}) + (UA)_A (T_{set} - T_{env}) \Delta t_m \qquad (10.63)$$

where, $(UA)_A$ is the auxiliary tank conductance for heat loss. Space heating loads can be input by the user or calculated according to the degree day concept (25) as

$$L_{SH} = (UA)_L \cdot DD \qquad (10.64)$$

where,

$(UA)_L$ is the overall conductance for heat loss from the house

DD is the number of degree-days within the month

The degree days (with a 18.3 degree C base) are part of the FCHART weather data base.

Auxiliary energy is added to match that portion of a load which the solar system cannot meet. For process heating or domestic hot water heating, the auxiliary device can be an electric, gas, or oil furnace. In this case, the user specifies the efficiency of the device, and the monthly purchased energy usage is

$$Q_{PUR} = Q_D - Q_S + (L - Q_D)\eta_A \qquad (10.65)$$

where,

η_A is the efficiency of the auxiliary device

For space heating, the primary auxiliary source can be an air-to-air heat pump or a conventional furnace. If a heat pump is chosen, a fossil fuel or electric source is used as a secondary auxiliary. The performance of parallel solar-heat pump systems are determined as presented by Anderson (26). In this method, it is assumed that the effect of the active solar system is to reduce the load that the heat pump must meet. The procedure for predicting the heat pump performance with this reduced load involves replacing the ambient temperature bin data required for the ASHRAE bin method (27) with a continuous generalized distribution. The heat pump and load energy rates are then integrated over this distribution. The monthly purchased energy usage for space heating systems with heat pump auxiliary is

$$Q_{PUR} = Q_D' - Q_S - Q_{ATM} + (L - Q_D')/\eta_A \qquad (10.66)$$

where,

Q_D' is the energy delivered to the load by both the delivery device and the heat pump auxiliary

Q_{ATM} is the energy absorbed by the evaporator of the auxiliary heat pump

References

1. Hottel, H.C., and Woertz, B.B., "Performance of Flat-Plate Solar Heat Collectors", Trans. ASME 64, 91 (1942).

2. ASHRAE STANDARD 93-77, (1977).

3. Klein, S.A., "Calculation of Flat-Plate Collector Utilizability", Solar Energy, 21, 393 (1978).

4. Whillier, A., "Solar Energy Collection and Its Utilization for House Heating", Ph.D. Thesis, M.I.T., Cambridge, Massachusetts (1953).

5. Liu, B.Y.H. and Jordan, R.C., "The Long-Term Average Performance of Flat-Plate Solar Energy Collectors", Solar Energy, 7, 53 (1963).

6. Theilacker, J.C., "An Investigation of Monthly-Average Utilizability for Flat-Plate Solar Collectors", M.S. Thesis, University of Wisconsin-Madison (1980).

7. Collares-Pereira, M. and Rabl, A., "Simple Procedure for Predicting Long Term Average Performance of Non-concentrating and of Concentrating Solar Collectors", Solar Energy, 23, 235 (1979).

8. Collares-Pereira, M. and Rabl, A., "The Average Distribution of Solar Radiation-Correlations Between Diffuse and Hemispherical and Between Daily and Hourly Insolation Values", Solar Energy, 22, 155 (1979).

9. Liu, B.Y.H. and Jordan, R.C., "The Interrelationship and Characteristic Distribution of Direct, Diffuse, and Total Solar Radiation", Solar Energy, 4, 3 (1960).

10. Duffie, J.A. and Beckman, W.A., Solar Engineering of Thermal Processes, Wiley-Interscience, New York (1980).

11. Klein, S.A., "Calculation of the Monthly-Average Transmittance-Absorptance Product", Solar Energy, in press.

12. Pettit, R.B., and Sowell, R.R., "Solar Absorptance and Emittance Properties", Journal of Vacuum Science Technology, 13 (1976).

13. Simon, F.F. and Buyco, E.A., "Outdoor Flat-Plate Collector Performances Prediction from Solar Simulator Test Data", NASA TMX-71707 (1975).

14. Brandemuehl, M.J. and Beckman, W.A., "Transmission of Diffuse Radiation Through CPC and Flat-Plate Collector Glazings", Solar Energy, in press.

15. Gaul, H. and Rabl, A., "Incidence Angle Modifier and Average Optical Efficiency of Parabolic Trough Collectors", Proceedings of the International Solar Energy Society, Atlanta, Georgia, Vol. 1, p. 547 (1979).

16. deWinter, F., "Heat Exchanger Penalties in Double-Loop Solar Water Heating Systems", Solar Energy, 17, 335 (1975).

17. Beckman, W.A., "Duct and Pipe Losses in Solar Energy Systems", Solar Energy, 21, 531 (1978).

18. Jones, D.E., Shaw, L.E., and Löf, G.O.G., "Air Leakage Effects on Active Air-Heating Solar Collector System Performance", Solar Heating and Cooling Systems Operational Results Conference Proceedings, Colorado Springs, Colorado (1978), p. 131.

19. Klein, S.A. and Beckman, W.A., "A General Design Method for Closed-Loop Solar Energy Systems", Solar Energy, 22, 269 (1979).

20. Svard, C.D. and Mitchell, J.W., "Design Procedure for Solar Assisted Series Heat Pump Systems", Proceedings of the AS/ISES 1980 Annual Meeting, Phoenix, Arizona, Vol. 3.1, p. 314.

21. Braun, J.E. and Duffie, J.A., "Design of Space Heating Systems Employing Seasonal Sensible Storage", Proceedings of the AS/ISES 1980 Annual Meeing, Phoenix, Arizona, Vol. 3.1, p. 276.

22. Pearsons, K.A., "Utilizability Design Method for Predicting the Long-Term Performance of Solar Hot Water Systems", M.S. Thesis, University of Wisconsin-Madison (1980).

23. Klein, S.A., Beckman, W.A., and Duffie, J.A., "A Design Procedure for Solar Heating Systems", Solar Energy, 18, 113 (1976).

24. Jurinak, J.J. and Abdel-Khalik, S.I., "Sizing Phase-Change Energy Storage Units for Air-Based Solar Heating Systems", Solar Energy, 22, 355 (1979)

25. ASHRAE, Handbook of Fundamentals (1978).

26. Anderson, J.V., "Procedures for Predicting the Performance of Air-to-Air Heat Pumps in Stand-Alone and Parallel Solar-Heat Pump Systems", M.S. Thesis, University of Wisconsin-Madison (1979).

27. ASHRAE Systems Handbook (1976).

APPENDIX A - Parameter Values

A.1 Default Values

SI Units

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COLLECTOR PARAMETERS
 C1. COLLECTOR AREA ..................................  50.00 M2
 C2. FR-UL PRODUCT ...................................   4.22 W/M2-DEG C
 C3. FR-TAU-ALPHA (NORMAL INCIDENCE) .................    .70
 C4. CONCENTRATION RATIO .............................   2.00
 C5. CPC ACCEPTANCE HALF-ANGLE .......................  30.00 DEGREES
 C6. NUMBER OF COVERS ................................   2.00
 C7. INDEX OF REFRACTION .............................   1.53
 C8. EXTINCTION COEFFICIENT X LENGTH (KL).............    .04
 C9. INCIDENCE ANGLE MODIFIER CONSTANT ...............    .00
 C10. COLLECTOR FLOW RATE * SPECIFIC HEAT/AREA .......  55.00 W/M2-DEG C
 C11. TRACKING AXIS (1=EW, 2=NS, 3=2-AXIS) ...........   3.00
 C12. COLLECTOR SLOPE ................................  43.00 DEGREES
 C13. COLLECTOR AZIMUTH ..............................    .00 DEGREES
 C14. GROUND REFLECTANCE .............................    .20
 C15. INCIDENCE ANGLE MODIFIERS (10,20,30,40,50,60,70,80 DEG.)
      1.00   .99   .98   .95   .90   .80   .63   .37

COLLECTOR-STORE TRANSFER PARAMETERS
 T1. EPS-CMIN OF COLLECTOR-STORE HX/COLLECTOR AREA ..  55.00 W/M2-DEG C
 T2. UA OF COLLECTOR INLET PIPE OR DUCT .............    .00 W/DEG C
 T3. UA OF COLLECTOR OUTLET PIPE OR DUCT ............    .00 W/DEG C
 T4. COLLECTOR DUCT LEAK RATE (PER CENT) ............  15.00
 T5. DUCT LEAK LOCATION (1=INLET,2=OUTLET,3=BOTH) ...   3.00

STORAGE UNIT PARAMETERS
 S1. TANK CAPACITY/COLLECTOR AREA ................... 350.00 KJ/DEG C-M2
 S2. STORAGE UNIT HEIGHT/DIAMETER RATIO .............   2.00
 S3. HEAT LOSS COEFFICIENT ..........................    .50 W/M2-DEG C
 S4. ENVIRONMENT TEMPERATURE (-1000 FOR TENV=TAMB) ..  20.00 DEG C
 S5. HOT WATER AUXILIARY TANK UA ....................   4.00 W/DEG C
 S6. HOT WATER AUX TANK ENVIRONMENT TEMPERATURE .....  20.00 DEG C
 S7. ROCK BED CAPACITY/COLLECTOR AREA ............... 350.00 KJ/DEG C-M2
 S8. PHASE-CHANGE VOLUME/COLLECTOR AREA (X1000)......  75.00 M3/M2
 S9. PHASE-CHANGE MATERIAL DENSITY .................. 1460.00 KG/M3
 S10. VOID FRACTION .................................    .25
 S11. SOLID PHASE SPECIFIC HEAT .....................   1.92 KJ/KG-DEG C
 S12. LIQUID PHASE SPECIFIC HEAT ....................   3.25 KJ/KG-DEG C
 S13. HEAT OF MELTING ............................... 251.00 KJ/KG
 S14. MELTING TEMPERATURE ...........................  32.00 DEG C

DELIVERY DEVICE PARAMETERS
 D1. EPS-CMIN OF LOAD HEAT EXCHANGER ................ 1200.00 W/DEG C
 D2. MINIMUM TEMPERATURE FOR HX OPERATION ...........  20.00 DEG C
 D3. DELIVERY HEAT PUMP NUMBER ......................   2.00
 D4. MINIMUM HEAT PUMP ABSORBER TEMPERATURE .........  10.00 DEG C
 D5. HEAT PUMP BYPASS TEMPERATURE ...................  40.00 DEG C

LOAD PARAMETERS
 L1. BUILDING UA .................................... 275.00 W/DEG C
 L2. ROOM TEMPERATURE ...............................  20.00 DEG C
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  L3. HOT WATER USE ...................................  300.00 LITERS/DAY
  L4. HOT WATER SET TEMPERATURE .......................   60.00 DEG C
  L5. WATER MAINS TEMPERATURE .........................   11.00 DEG C
  L6. TOTAL PROCESS OR SPACE HEATING LOAD .............  500.00 MJ/DAY
  L7. HOURS PER DAY ...................................   24.00
  L8. LOAD RETURN TEMPERATURE .........................   21.00 DEG C

AUXILIARY PARAMETERS
  A1. AUXILIARY FUEL TYPE (1=GAS,2=ELEC,3=OIL) .......    2.
  A2. AUXILIARY DEVICE EFFICIENCY .....................    1.00
  A3. HOT WATER AUXILIARY FUEL (1=GAS,2=ELEC,3=OIL) ..    2.
  A4. AUXILIARY WATER HEATER EFFICIENCY ...............    1.00
  A5. AUXILIARY HEAT PUMP NUMBER ......................    1.

ECONOMIC PARAMETERS
  E1. ECONOMIC OUTPUT DETAIL (1,2 OR 3) ...............    2.00
  E2. REFERENCE OR COMPARISON SYSTEM (1 OR 2) .........    1.00
  E3. CALCULATE RATE OF RETURN (YES=1,NO=2) ...........    2.00
  E4. INCOME PRODUCING BUILDING (YES=1,2=NO) ..........    2.00
  E5. DEPRC: STR,LN.=1,DC.BAL.=2,SM-YR-DGT=3,NONE=4 ..    1.00
  E6. CONSIDER FEDERAL TAX CREDITS (YES=1,2=NO) ......    1.00
  E7. LENGTH OF ANALYSIS ..............................   20.00 YEARS
  E8. TAX CREDITABLE SYSTEM BASE COST ................$ 6000.00
  E9. NON-TAX CREDITABLE SYSTEM BASE COST ............$     .00
  E10. ANNUAL INCREASE IN PURCHASED ENERGY DEMAND ....     .00 %/YR
  E11. TERM OF MORTGAGE ..............................   20.00 YEARS
  E12. DOWN PAYMENT (% OF ORIGINAL INVESTMENT) .......   10.00 %
  E13. MORTGAGE ANNUAL INTEREST RATE .................    8.00 %
  E14. RESALE VALUE (% OF ORIGINAL INVESTMENT) .......     .00 %
  E15. ANNUAL NOMINAL (MARKET) DISCOUNT RATE .........    8.00 %
  E16. EXTRA INSUR.,MAINT. IN YEAR 1 (% OF ORIG.INV.)    1.00 %
  E17. ANNUAL % INCREASE IN ABOVE EXPENSES ...........    6.00 %
  E18. EFFECTIVE FEDERAL-STATE INCOME TAX RATE .......   35.00 %
  E19. TRUE PROP. TAX RATE PER $ OF ORIGINAL INVEST ..    2.00 %
  E20. ANNUAL % INCREASE IN PROPERTY TAX RATE ........    6.00 %/YR
  E21. STATE CREDIT IN TIER ONE.......................   24.00 %
  E22. STATE CREDIT TIER ONE BREAK...................$10000.00
  E23. STATE CREDIT IN TIER TWO.......................     .00 %
  E24. STATE CREDIT TIER TWO BREAK...................$10000.00
  E25. USEFUL LIFE FOR DEPREC. PURPOSES ..............   20.00 YEARS
  E26. % OF ST. LINE DEP. RATE (DC. BAL. DEPRC.) .....  150.00 %
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English Units

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COLLECTOR PARAMETERS
 C1. COLLECTOR AREA .................................  538.20 FT2
 C2. FR-UL PRODUCT ..................................     .74 BTU/HR-FT2-DEG F
 C3. FR-TAU-ALPHA (NORMAL INCIDENCE) ................     .70
 C4. CONCENTRATION RATIO ............................    2.00
 C5. CPC ACCEPTANCE HALF-ANGLE ......................   30.00 DEGREES
 C6. NUMBER OF COVERS ...............................    2.00
 C7. INDEX OF REFRACTION ............................    1.53
 C8. EXTINCTION COEFFICIENT X LENGTH (KL)............     .04
 C9. INCIDENCE ANGLE MODIFIER CONSTANT ..............     .00
 C10. COLLECTOR FLOW RATE * SPECIFIC HEAT/AREA ......    9.69 BTU/HR-FT2-DEG F
 C11. TRACKING AXIS (1=EW, 2=NS, 3=2-AXIS) ..........    3.00
 C12. COLLECTOR SLOPE ...............................   43.00 DEGREES
 C13. COLLECTOR AZIMUTH .............................     .00 DEGREES
 C14. GROUND REFLECTANCE ............................     .20
 C15. INCIDENCE ANGLE MODIFIERS (10,20,30,40,50,60,70,80 DEG.)
      1.00    .99    .98    .95    .90    .80    .63    .37

COLLECTOR-STORE TRANSFER PARAMETERS
 T1. EPS-CMIN OF COLLECTOR-STORE HX/COLLECTOR AREA ..    9.69 BTU/HR-FT2-DEG F
 T2. UA OF COLLECTOR INLET PIPE OR DUCT .............     .00 BTU/HR-DEG F
 T3. UA OF COLLECTOR OUTLET PIPE OR DUCT ............     .00 BTU/HR-DEG F
 T4. COLLECTOR DUCT LEAK RATE (PER CENT) ............   15.00
 T5. DUCT LEAK LOCATION (1=INLET,2=OUTLET,3=BOTH) ...    3.00

STORAGE UNIT PARAMETERS
 S1. TANK CAPACITY/COLLECTOR AREA ...................   17.12 BTU/DEG F-FT2
 S2. STORAGE UNIT HEIGHT/DIAMETER RATIO .............    2.00
 S3. HEAT LOSS COEFFICIENT ..........................     .09 BTU/HR-FT2-DEG F
 S4. ENVIRONMENT TEMPERATURE (-1000 FOR TENV=TAMB) ..   68.00 DEG F
 S5. HOT WATER AUXILIARY TANK UA ....................    7.58 BTU/HR-DEG F
 S6. HOT WATER AUX TANK ENVIRONMENT TEMPERATURE .....   68.00 DEG F
 S7. ROCK BED CAPACITY/COLLECTOR AREA ...............   17.12 BTU/DEG F-FT2
 S8. PHASE-CHANGE VOLUME/COLLECTOR AREA (X1000)......  246.07 FT3/FT2
 S9. PHASE-CHANGE MATERIAL DENSITY ..................   91.15 LB/FT3
 S10. VOID FRACTION .................................     .25
 S11. SOLID PHASE SPECIFIC HEAT .....................     .46 BTU/LB-DEG F
 S12. LIQUID PHASE SPECIFIC HEAT ....................     .78 BTU/LB-DEG F
 S13. HEAT OF MELTING ...............................  107.90 BTU/LB
 S14. MELTING TEMPERATURE ...........................   89.60 DEG F

DELIVERY DEVICE PARAMETERS
 D1. EPS-CMIN OF LOAD HEAT EXCHANGER ................ 2274.72 BTU/HR-DEG F
 D2. MINIMUM TEMPERATURE FOR HX OPERATION ...........   68.00 DEG F
 D3. DELIVERY HEAT PUMP NUMBER ......................    2.00
 D4. MINIMUM HEAT PUMP ABSORBER TEMPERATURE .........   50.00 DEG F
 D5. HEAT PUMP BYPASS TEMPERATURE ...................  104.00 DEG F

LOAD PARAMETERS
 L1. BUILDING UA ....................................  521.29 BTU/HR-DEG F
 L2. ROOM TEMPERATURE ...............................   68.00 DEG F
 L3. HOT WATER USE ..................................   79.26 GALLONS/DAY
 L4. HOT WATER SET TEMPERATURE .......................  140.00 DEG F
 L5. WATER MAINS TEMPERATURE .........................   51.80 DEG F
 L6. TOTAL PROCESS OR SPACE HEATING LOAD .............  473.90 MBTU/DAY
 L7. HOURS PER DAY ...................................   24.00
 L8. LOAD RETURN TEMPERATURE .........................   69.80 DEG F

AUXILIARY PARAMETERS
 A1. AUXILIARY FUEL TYPE (1=GAS,2=ELEC,3=OIL) .......     2.
 A2. AUXILIARY DEVICE EFFICIENCY .....................    1.00
 A3. HOT WATER AUXILIARY FUEL (1=GAS,2=ELEC,3=OIL) ..     2.
 A4. AUXILIARY WATER HEATER EFFICIENCY ...............    1.00
 A5. AUXILIARY HEAT PUMP NUMBER ......................    1.

ECONOMIC PARAMETERS
 E1. ECONOMIC OUTPUT DETAIL (1,2 OR 3) ...............    2.00
 E2. REFERENCE OR COMPARISON SYSTEM (1 OR 2) .........    1.00
 E3. CALCULATE RATE OF RETURN (YES=1,NO=2) ...........    2.00
 E4. INCOME PRODUCING BUILDING (YES=1,2=NO) ..........    2.00
 E5. DEPRC: STR,LN.=1,DC.BAL.=2,SM-YR-DGT=3,NONE=4 ..    1.00
 E6. CONSIDER FEDERAL TAX CREDITS (YES=1,2=NO) ......    1.00
 E7. LENGTH OF ANALYSIS ..............................   20.00 YEARS
 E8. TAX CREDITABLE SYSTEM BASE COST ...............$ 6000.00
 E9. NON-TAX CREDITABLE SYSTEM BASE COST ...........$      .00
 E10. ANNUAL INCREASE IN PURCHASED ENERGY DEMAND ....      .00 %/YR
 E11. TERM OF MORTGAGE ...............................   20.00 YEARS
 E12. DOWN PAYMENT (% OF ORIGINAL INVESTMENT) .......   10.00 %
 E13. MORTGAGE ANNUAL INTEREST RATE ..................    8.00 %
 E14. RESALE VALUE (% OF ORIGINAL INVESTMENT) .......      .00 %
 E15. ANNUAL NOMINAL (MARKET) DISCOUNT RATE .........    8.00 %
 E16. EXTRA INSUR.,MAINT. IN YEAR 1 (% OF ORIG.INV.)     1.00 %
 E17. ANNUAL % INCREASE IN ABOVE EXPENSES ...........    6.00 %
 E18. EFFECTIVE FEDERAL-STATE INCOME TAX RATE .......   35.00 %
 E19. TRUE PROP. TAX RATE PER $ OF ORIGINAL INVEST ..    2.00 %
 E20. ANNUAL % INCREASE IN PROPERTY TAX RATE ........    6.00 %/YR
 E21. STATE CREDIT IN TIER ONE........................   24.00 %
 E22. STATE CREDIT TIER ONE BREAK...................$10000.00
 E23. STATE CREDIT IN TIER TWO........................     .00 %
 E24. STATE CREDIT TIER TWO BREAK...................$10000.00
 E25. USEFUL LIFE FOR DEPREC. PURPOSES ...............   20.00 YEARS
 E26. % OF ST. LINE DEP. RATE (DC. BAL. DEPRC.) .....  150.00 %
```

A.2 Parameter Restrictions

Upon executing the RUN command, FCHART checks the "reasonableness" of the parameters associated with the system that has been specified. In many cases, the restrictions on allowable values should be obvious by the nature of the parameter. For instance, a user cannot specify negative collector areas (C1) or a load occurring more than 24 hours per day (L7) without encountering error messages. Also, certain parameters are set up to allow user options, such as choices of tracking axis orientation for imaging collectors (C11) or economic output detail (E1). Specifying options other than those suggested by the program will result in error messages. Other restrictions on certain parameters are imposed as a result of correlations or assumptions employed in the design methods and are dependant upon the system chosen.

Liquid-Based Systems

For liquid-based systems (process, space, or domestic hot water heating) two parameters have restictions imposed by the nature of the design methods. The tank capacitance per unit collector area must be greater than or equal to 150 KJ/m²-°C (7.34 Btu/ft²-°F).

It is important to note that when the delivery device is a heat exchanger, the minimum useful temperature (D2) must be greater than or equal to the heat exchanger cold side inlet temperature (L8) to insure that energy supplied to the load is non-negative. This must also be the case for the heat pump bypass temperature (D5) when a heat pump is the delivery device.

Air-Based Systems

The design method for air-based systems involves a correlation generated from many detailed simulation results. The correlation is only applicable for collector capacitance rates per unit area (C10) between 6.09 W/m²-°C (1.08 Btu/hr-ft²-°C) and 24.5 W/m²-°C (4.32 Btu/hr-ft²-°C). The storage capacitance per unit area must be less than or equal to 1260 KJ/m²-°C (60 Btu/ft²-°C) and greater than or equal to 157.5 KJ/m²-°C (7.5 Btu/ft²-°F). If a rock bed is the storage device, then parameter S7 must be within this range. If a phase change energy storage (PCES) unit is chosen, an effective capacitance defined by Jurinak (24) is

$$(MC_p)_{eff} = M\left[\frac{a_1\lambda}{T_m^2} + \left(1+\frac{a_2^2}{T_m^2}\right)C_S + \frac{a_2}{T_m^2}C_L\right] \qquad (A.1)$$

where,

M is the phase change material mass
λ is the latent heat (S13)
T_m is the melting temperature (S14)

C_S is the solid phase specific heat (S11)
C_L is the liquid phase specific heat (S12)
a_1 = 18.3 °C (65 °F)
a_2 = 4.28 °C (39.7 ° F)

Equation (A.1) is only applicable for melting temperatures (S14) greater than or equal to 24°C (75.2°F) and less than or equal to 50 °C (122 °F). Applying the restriction for storage capacitance per unit area to equation (A.1) ,the allowable range for PCES volume (S8) can be written in terms of other parameters as

$$\frac{(MC_p)_{min}}{(1-f_V)\rho_S(C_p)_{eff}} \leq V \leq \frac{(MC_p)_{max}}{(1-f_V)\rho_S(C_p)_{eff}} \qquad (A.2)$$

where,

V	is the PCES unit volume per unit area (S8)
$(MC_p)_{min}$	is the minimum allowable storage capacitance per unit area = 157.5 $KJ/m^2\text{-}^{\circ}C$ (7.5 $Btu/ft^2\text{-}^{\circ}F$)
$(MC_p)_{max}$	is the maximum allowable storage capacitance per unit area = 1260 $KJ/m^2\text{-}^{\circ}C$ (60 $Btu/ft^2\text{-}^{\circ}F$)
f_V	is the PCES unit void fraction (S10)
ρ_S	is the density of the phase change material (S9)

$$(C_p)_{eff} = \frac{a_1\lambda}{T_m^2} + (1+\frac{a_2^2}{T_m^2})C_S + \frac{a_2^2}{T_m^2}C_L$$

A.3 Sample Worksheets

SI Units

Flat-Plate	CPC	E.W. Axis Tracking	N.S. Axis Tracking	2 - Axis Tracking	COLLECTOR PARAMETERS		
X	X	X	X	X	C1. Collector Area	____	m^2
X	X	X	X	X	C2. FR-UL Product	____	W/m^2-°C
X	X	X	X	X	C3. FR-TAU-ALPHA (Normal Incidence)	____	
	X	X	X	X	C4. Concentration Ratio	____	
	X				C5. CPC Acceptance Half-Angle	____	
X					C6. Number of Covers	____	
X					C7. Index of Refraction	____	
X					C8. Extinction Coefficient·Length (KL)	____	
X					C9. Incidence Angle Modifier Constant*	____	
X	X	X	X	X	C.10 Collector Flowrate·Specific Heat/Area	____	W/m^2-°C
		X	X	X	C.11 Tracking Axis (1 = EW, 2 = NS, 3 = 2-Axis)	____	
X	X		X		C.12 Collector Slope** ________________	____	Degrees
X	X	X			C.13 Collector Azimuth** ________________	____	
X	X	X	X	X	C.14 Ground Reflectance** ________________	____	
	X	X	X		C.15 Incidence Angle Modifiers (10,20,30,40,50,60,70,80 Degrees) ________________________________		

* If C9 is set to zero, parameters C6, C7, and C8 are used. If C6 is set less than or equal to zero, parameter C15 is used.

** Twelve values may be specified for parameters C12, C13, and C14. Only one value is necessary if these parameters do not vary by month.

Heat Exchanger	Duct or Pipe Heat Loss	Air Leaks	TRANSFER PARAMETERS		
X			T1. EPS - CMIN of Collector-Store HX/Collector Area	_____	W/m^2-°C
	X		T2. UA of Collector Inlet Pipe or Duct	_____	W/°C
	X		T3. UA of Collector Outlet Pipe or Duct	_____	W/°C
		X	T4. Collector Duct Leak Rate (percent)	_____	
		X	T5. Duct Leak Location (1 = INLET, 2 = OUTLET, 3 = BOTH)	_____	

Water	Rock - Bed	Phase Change	STORAGE PARAMETERS		
X			S1. Tank Capacity/Collector Area	_____	KJ/m^2-°C
X			S2. Storage Unit Height/Diameter Ratio	_____	
X			S3. Heat Loss Coefficient	_____	W/m^2-°C
X			S4. Environmental Temperature (-1000 for TENV=TAMB)	_____	°C
X	X	X	S5. Hot Water Auxiliary Tank UA*	_____	W/°C
X	X	X	S6. Hot Water Aux Tank Environmental Temperature*	_____	°C
	X		S7. Rock Bed Capacity/Collector Area	_____	KJ/m^2-°C
		X	S8. Phase Change Volume/Collector Area	_____	m^3/m^2
		X	S9. Phase Change Material Density	_____	KG/m^3
		X	S10. Void Fraction	_____	
		X	S11. Solid Phase Specific Heat	_____	KJ/KG-°C
		X	S12. Liquid Phase Specific Heat	_____	KJ/KG-°C
		X	S13. Heat of Melting	_____	KJ/KG
		X	S14. Melting Temperature	_____	°C

* Parameters S5 and S6 are necessary only when domestic hot water heating is considered.

Heat Exchanger	Heat Pump	DELIVERY DEVICE PARAMETERS		
X	X	D1. EPS-CMIN of Load Heat Exchanger	____	W/°C
X		D2. Minimum Temperature for Hx Operation	____	°C
	X	D3. Delivery Heat Pump Number	____	
	X	D4. Minimum Heat Pump Absorber Temperature	____	°C
	X	D5. Heat Pump Bypass Temperature	____	°C

Process Heating	Space Heating	Water Heating	Combined	LOAD PARAMETERS		
	X		X	L1. Building UA	____	W/°C
	X		X	L2. Room Temperature	____	°C
		X	X	L3. Hot Water Use*	____	L/Day
		X	X	L4. Hot Water Set Temperature*	____	°C
		X	X	L5. Water Mains Temperature*	____	°C
X	X		X	L6. Total Process or Space Heating Load*	____	MJ/Day
X				L7. Hours per Day	____	
X				L8. Load Return Temperature	____	°C

* Twelve values may be specified for parameters L3 - L6. Only one value is necessary if these parameters do not vary by month. If L6 is specified for space heating systems, then L1 and L2 are not necessary.

Fuel	Heat Pump	AUXILIARY PARAMETERS	
X	X	A1. Auxiliary Fuel Type (1 = GAS, 2 = ELEC, 3 = OIL)	______
X	X	A2. Auxiliary Device Efficiency	______
X	X	A3. Hot Water Auxiliary Fuel (1 = GAS, 2 = ELEC, 3 = OIL)*	______
X	X	A4. Auxiliary Water Heater Efficiency*	______
	X	A5. Auxiliary Heat Pump Number**	______

* Parameters A3 and A4 are necessary when domestic hot water heating is considered.

** Parameter A5 is only applicable for space heating.

ECONOMIC PARAMETERS

E1. Economic Output Detail (1, 2 or 3) ______

E2. Reference or Comparison System (1 or 2) ______

E3. Calculate Rate of Return (Yes=1, No=2) ______

E4. Income Producing Building (Yes=1, No=2) ______

E5. DEPRC: STR,LN.=1, DC.BAL.=2, SM-YR-DGT=3, NONE=4 ______

E6. Consider Federal Tax Credits (Yes=1, No=2) ______

E7. Length of Analysis ______ Years

E8. Tax Creditable System Base Cost $ ______

E9. Non-tax Creditable System Base Cost ______

E10. Annual Increase in Purchased Energy Demand ______ %/Yr

E11. Term of Mortgage ______ Years

E12. Down Payment (% of original investment) ______ %

E13. Mortgage Annual Interest Rate ______ %

E14. Resale Value (% of original investment) ______ %

E15. Annual Nominal (market) Discount Rate ______ %

E16. Extra Insur., Maint. in Year 1 (% of original investment) ______ %

E17. Annual % Increase in Above Expenses ______ %

E18. Effective Federal-State Income Tax Rate ______ %

E19. True Prop. Tax Rate per $ of Original Investment ______ %

E20. Annual % Increase in Property Tax Rate ______ %/Yr

E21. State Credit in Tier One ______ %

E22. State Credit Tier One Break $ ______

E23. State Credit In Tier Two ______ %

E24. State Credit Tier Two Break $ ______

E25. Useful Life for Deprec. Purposes ______ Years

E26. % of St. Line Dep. Rate (DC. BAL. DEPRC.) ______ %

English Units

Flat-Plate	CPC	E.W. Axis Tracking	N.S. Axis Tracking	2 - Axis Tracking	COLLECTOR PARAMETERS		
X	X	X	X	X	C1. Collector Area	______	ft^2
X	X	X	X	X	C2. FR-UL Product	______	BTU/hr-ft^2-°F
X	X	X	X	X	C3. FR-TAU-ALPHA (Normal Incidence)	______	
	X	X	X	X	C4. Concentration Ratio	______	
	X				C5. CPC Acceptance Half-Angle	______	
X					C6. Number of Covers	______	
X					C7. Index of Refraction	______	
X					C8. Extinction Coefficient·Length (KL)	______	
X					C9. Incidence Angle Modifier Constant*	______	
X	X	X	X	X	C.10 Collector Flowrate·Specific Heat/Area	______	BTU/hr-ft^2-°F
		X	X	X	C.11 Tracking Axis (1 = EW, 2 = NS, 3 = 2-Axis)	______	
X	X		X		C.12 Collector Slope**	______	Degrees
X	X	X			C.13 Collector Azimuth**	______	Degrees
X	X	X	X	X	C.14 Ground Reflectance**	______	
	X	X	X		C.15 Incidence Angle Modifiers (10,20,30,40,50,60,70,80 Degrees) ______		

* If C9 is set to zero, parameters C6, C7, and C8 are used. If C6 is set less than or equal to zero, parameter C15 is used.

** Twelve values may be specified for parameters C12, C13, and C14. Only one value is necessary if these parameters do not vary by month.

Heat Exchanger	Duct or Pipe Heat Loss	Air Leaks	TRANSFER PARAMETERS		
X			T1. EPS - CMIN of Collector-Store HX/Collector Area	____	BTU/hr-ft^2-°F
	X		T2. UA of Collector Inlet Pipe or Duct	____	BTU/hr-°F
	X		T3. UA of Collector Outlet Pipe or Duct	____	BTU/hr-°F
		X	T4. Collector Duct Leak Rate (percent)	____	
		X	T5. Duct Leak Location (1 = INLET, 2 = OUTLET, 3 = BOTH)	____	

Water	Rock - Bed	Phase Change	STORAGE PARAMETERS		
X			S1. Tank Capacity/Collector Area	____	BTU/ft^2-°F
X			S2. Storage Unit Height/Diameter Ratio	____	
X			S3. Heat Loss Coefficient	____	BTU/hr-ft^2-°F
X			S4. Environmental Temperature (-1000 for TENV=TAMB)	____	°F
X	X	X	S5. Hot Water Auxiliary Tank UA*	____	BTU/hr-°C
X	X	X	S6. Hot Water Aux Tank Environmental Temperature*	____	°F
	X		S7. Rock Bed Capacity/Collector Area	____	BTU/ft^2-°C
		X	S8. Phase Change Volume/Collector Area	____	ft^3/ft^2
		X	S9. Phase Change Material Density	____	lb/ft^3
		X	S10. Void Fraction	____	
		X	S11. Solid Phase Specific Heat	____	BTU/lb-°F
		X	S12. Liquid Phase Specific Heat	____	BTU/lb-°F
		X	S13. Heat of Melting	____	BTU/lb
		X	S14. Melting Temperature	____	°F

* Parameters S5 and S6 are necessary only when domestic hot water heating is considered.

Heat Exchanger	Heat Pump	DELIVERY DEVICE PARAMETERS		
X	X	D1. EPS-CMIN of Load Heat Exchanger	_____	BTU/hr-°F
X		D2. Minimum Temperature for Hx Operation	_____	°F
	X	D3. Delivery Heat Pump Number	_____	
	X	D4. Minimum Heat Pump Absorber Temperature	_____	°F
	X	D5. Heat Pump Bypass Temperature	_____	°F

Process Heating	Space Heating	Water Heating	Combined	LOAD PARAMETERS		
	X		X	L1. Building UA	_____	BTU/hr-°F
	X		X	L2. Room Temperature	_____	°F
		X	X	L3. Hot Water Use*	_____	Gallons/Day
		X	X	L4. Hot Water Set Temperature*	_____	°F
		X	X	L5. Water Mains Temperature*	_____	°F
X	X		X	L6. Total Process or Space Heating Load*	_____	MBTU/Day
X				L7. Hours per Day	_____	
X				L8. Load Return Temperature	_____	°F

* Twelve values may be specified for parameters L3 - L6. Only one value is necessary if these parameters do not vary by month. If L6 is specified for space heating systems, then L1 and L2 are not necessary.

Fuel	Heat Pump	AUXILIARY PARAMETERS	
X	X	A1. Auxiliary Fuel Type (1 = GAS, 2 = ELEC, 3 = OIL)	______
X	X	A2. Auxiliary Device Efficiency	______
X	X	A3. Hot Water Auxiliary Fuel (1 = GAS, 2 = ELEC, 3 = OIL)*	______
X	X	A4. Auxiliary Water Heater Efficiency*	______
	X	A5. Auxiliary Heat Pump Number**	______

* Parameters A3 and A4 are necessary when domestic hot water heating is considered.

** Parameter A5 is only applicable for space heating.

ECONOMIC PARAMETERS

E1. Economic Output Detail (1, 2 or 3) ______
E2. Reference or Comparison System (1 or 2) ______
E3. Calculate Rate of Return (Yes=1, No=2) ______
E4. Income Producing Building (Yes=1, No=2) ______
E5. DEPRC: STR,LN.=1, DC.BAL.=2, SM-YR-DGT=3, NONE=4 ______
E6. Consider Federal Tax Credits (Yes=1, No=2) ______
E7. Length of Analysis ______ Years
E8. Tax Creditable System Base Cost $ ______
E9. Non-tax Creditable System Base Cost ______
E10. Annual Increase in Purchased Energy Demand ______%/Yr
E11. Term of Mortgage ______ Years
E12. Down Payment (% of original investment) ______%
E13. Mortgage Annual Interest Rate ______%
E14. Resale Value (% of original investment) ______%
E15. Annual Nominal (market) Discount Rate ______%
E16. Extra Insur., Maint. in Year 1 (% of original investment) ______%
E17. Annual % Increase in Above Expenses ______%
E18. Effective Federal-State Income Tax Rate ______%
E19. True Prop. Tax Rate per $ of Original Investment ______%
E20. Annual % Increase in Property Tax Rate ______%/Yr
E21. State Credit in Tier One ______%
E22. State Credit Tier One Break $ ______
E23. State Credit In Tier Two ______%
E24. State Credit Tier Two Break $ ______
E25. Useful Life for Deprec. Purposes ______ Years
E26. % of St. Line Dep. Rate (DC. BAL. DEPRC.) ______%

APPENDIX B

Weather Data Used in FCHART 4.0

The following pages contain three listings of the locations contained in the weather data bank. Appendix B.1 provides a list of the 10 commonly used Canadian cities in the internal data base. Appendix B.2 is arranged alphabetically by province, while Appendix B.3 is arranged alphabetically by city. In the second listing the monthly values for degree days (based on 18 C), mean ambient temperature (C) and solar insolation (MJ/M2-DAY) are provided for each location. Each location name is preceded by its call number.

APPENDIX B.1

Default Locations in the Internal Base

CALL NO.	CITY	PROVINCE	LATITUDE
12	CHARLOTTETOWN	PEI	46.28
23	EDMONTON	ALTA	53.57
29	FREDERICTON	NB	45.87
34	HALIFAX	NS	44.65
47	MONTREAL INT'L	QUE	45.50
53	OTTAWA INT'L	ONT	45.32
69	SASKATOON	SASK	52.23
84	TORONTO INT'L	ONT	43.68
88	VANCOUVER INT'L	BC	49.28
94	WINNIPEG INT'L	MAN	49.90

APPENDIX B.2

ALPHABETICAL LISTING

ALBERTA

6	Banff	ALTA
9	Calgary Int'l	ALTA
17	Coronation	ALTA
23	Edmonton	ALTA
25	Fort McMurry	ALTA
33	Grande Prairie	ALTA
36	Jasper	ALTA
41	Lethbridge	ALTA
44	Medicine Hat	ALTA
54	Peace River	ALTA
62	Red Deer	ALTA

BRITISH COLUMBIA

1	Abbotsford	BC
7	Blue River	BC
10	Castlegar	BC
16	Comox	BC
18	Cranbrook	BC
26	Fort Nelson	BC
28	Fort St. John	BC
37	Kamloops	BC
55	Penticton	BC
56	Port Hardy	BC
59	Prince George	BC
60	Prince Rupert	BC
65	Revestoke	BC
79	Terrace	BC
88	Vancouver Int'l	BC
89	Victoria Int'l	BC
92	Williams Lake	BC

MANITOBA

8	Brandon	MAN
15	Churchill	MAN
20	Dauphin	MAN
80	The Pas	MAN
81	Thompson	MAN
94	Winnipeg Int'l	MAN

NEW BRUNSWICK

11	Charlo	NB
13	Chatham	NB
29	Fredericton	NB
45	Moncton	NB
68	Saint John	NB

NEWFOUNDLAND

31	Gander Int'l	NFLD
32	Goose Bay	NFLD
74	St. John's	NFLD
75	Stephenville	NFLD

NORTH WEST TERRITORIES

2	Aklavik	NWT
27	Fort Smith	NWT
30	Frobisher Bay	NWT
35	Inuvik	NWT
64	Resolute	NWT
96	Yellowknife	NWT

NOVA SCOTIA

34	Halifax	NS
78	Sydney	NS
86	Truro	NS
95	Yarmouth	NS

ONTARIO

3	Armstrong	ONT
22	Earlton	ONT
38	Kapuskasing	ONT
39	Kenora	ONT
40	Kingston	ONT
42	London	ONT
48	Mossonee	ONT
49	Mount Forest	ONT
50	Muskoka	ONT
52	North Bay	ONT
53	Ottawa Int'l	ONT
73	Simco	ONT
76	Sudbury	ONT
82	Thunder Bay	ONT
83	Timmins	ONT
84	Toronto Int'l	ONT
85	Trenton	ONT
91	Wiarton	ONT
93	Windsor	ONT

PRINCE EDWARD ISLAND

12	Charlottetown	PEI

QUEBEC

4	Bagotville	QUE
5	Baie Comeau	QUE
14	Chibougamau	QUE
43	Maniwaki	QUE
46	Mont Joli	QUE
47	Montreal Int'l	QUE
51	Natashquan	QUE
57	Pose de la Ba	QUE
61	Quebec	QUE
66	Riviere au Ren	QUE
67	Rivier du Loop	QUE
70	Schefferville	QUE
71	Sept-Illes	QUE
72	Scherbrooke	QUE
87	Val D'or	QUE

SASKATCHEWAN

19	Cree Lake	SASK
24	Estevan	SASK
58	Prince Albert	SASK
63	Regina	SASK
69	Saskatoon	SASK
77	Swift Current	SASK
97	Yorkton	SASK

YUKON

21	Dawson	YUK
90	White Horse	YUK

APPENDIX C - Extending FCHART's Capabilities

There are ways in which you can use version 4.1 to consider systems or conditions that you may not have thought possible. These are outlined as follows:

Single-Tank DHW

Single-tank water heating systems can be considered in FCHART 4.1 by defining an effective two-tank system. The auxiliary tank of this imaginary system is assumed to have a (UA) (parameter S5) of the portion of the single tank above the heating element. The preheat tank is considered to have the same total capacitance (parameter S1) and loss coefficient (parameter S3) as the single tank. Studies at the Solar Lab have shown that the simulated performance of one-tank and effective two-tank (as defined above) systems is very similar.

In-Tank Heat Exchanger

An in-tank collector-storage heat exchanger can be considered in FCHART 4.1 by appropriately defining parameter T1. For this situation, this parameter should be the product of the heat exchanger effectiveness and the capacitance rate per unit collector area of the collector working fluid. This scheme assumes that the heat exchanger effectiveness is constant, independent of the operating temperatures. Experiments conducted at the Solar Lab have indicated that this is a reasonable assumption. The effectiveness for in-tank heat exchanges is defined as the actual heat transfer across the heat exchanger divided by the heat transfer if the temperature of the fluid leaving the heat exchanger were equal to the temperature in the storage tank.

Commercial Federal Tax Credit

FCHART 4.1 allows the user to consider Federal tax credits by setting parameter E6 to 1. In doing so, however, the current rate for residential buildings is assumed (40% for up to $10,000). If for any reasons the Federal credits for a particular application differ from these, E6 should be set to 2. In most cases, they may be lumped in with the state credits. Three situations may arise which are treated as follows:

(1) If the state credit is only single tier, then the Federal credit can be included as an additional tier. In this case, E21 should be the sum of the state and Federal credits. E22 should be the minimum of the upper ceilings for the state and Federal credits. E23 and E24 should correspond to the credit with the higher ceiling.

(2) If there is a two-tier state tax credit and the ceiling for Federal credits is equal to one of the tier breaks, then E21 should be set equal to the sum of the state credit in tier one and the Federal credit. In addition, if the Federal ceiling is equal to E24, E23 should be the sum of the state credit in tier two and the Federal credit. Otherwise, E23 is just the state credit in tier two.

(3) If there is a two-tier state tax credit and the ceiling for Federal credits is not equal to one of the tier breaks, then an alternative approach is necessary. A modified state tax credit rate for the second tier can be calculated as

$$E23 = \frac{\text{(total state \& federal credits (\$)) - (state credits in tier one (\$))}}{\text{(the minimum of E8 and E24) - E22}}$$

If OPTIMIZATION or LOOPing is performaed and the variable parameter(s) are eligible for tax credits, this scheme will not work, since the total credits cannot be known apriori.

Large Systems

Some users have expressed an interest in using FCHART 4.1 to study very large systems. Due to formatting restrictions, there is a limit on the magnitude of certain parameters and results that are printed. For instance, a collector area larger than or equal to 100,000 (ft^2 or m^2) will not appear as such in the list of parameters. Energy quantities larger than or equal to 100,000 (GJ's or MMBTU's) will not be printed correctly in the thermal performance table. A way around this problem is to scale down the system parameters appropriately so that the energy and cost results are all scaled down equally. A summary of the steps necessary to do this are as follows:

(1) Pick a scaling factor N. All energy and cost results will be scaled down by this factor. In other words, these FCHART results will be 1/N times the desired results. The fractions of the load met by the different energy sources will not be scaled in any manner.

(2) Divide the actual values of the following parameters by N (if applicable to the system under consideration):

C1, T2, T3, S5, D1, L1,
L3, L6, E8, E9

The tank loss coefficient must be scaled somewhat differently. The scaled value, S3', is found in terms of the actual value, S3, as

$$S3' = S3/N^{1/3}$$

(3) Since the Federal tax credit ceiling is built into the program, the Federal credits must be turned off (E6 = 2). These credits can be included in the state credits as outlined earlier in this letter. The resulting state cred· ceilings, E22 and E24, should be divided by N.

(4) If heat pump data is required, divide the energy absorbed, capacity, and work input data by N.

(5) When fuel costs are entered with a block rate structure, the maximum use associated with each block should be divided by N.

(6) Multiply all results which are energy quantities or costs by N to obtain the actual results.

POOR

QUALITY

ORIGINAL